BOTANY THEORY NOTES FOR

I BSc.

SECOND SEMESTER

PAPER II

DIVERSITY OF NON-VASCULAR PLANTS MYCOLOGY, PLANT PATHOLOGY, BRYOPHYTES AND PLANT ANATOMY

FUNGI

Fungi (singular fungus — mushroom, from Latin) are nucleated, spore bearing, achlorophyllous organisms which generally reproduce sexually and asexually, and whose usually filamentous branched somatic structures are typically surrounded by cell walls containing cellulose or chitin, or both (Alexopoulos, 1952).

In simpler words it may also be defined as "non-green, nucleated thallophytes". The common examples of fungi are the yeasts, molds, mushrooms, polyporus, puff balls, rusts and smuts. More than 5,000 genera and 50,000 species of fungi have been recorded, but their number may be much more than the actual record. The subject which deals with fungi is known as Mycology (mykes — mushroom; logos— study) and the concerned scientist is called mycologist.

Characteristics of Fungi:

1. Fungi are cosmopolitan in distribution i.e., they can grow in any place where life is possible.
2. They are heterotrophic in nature due to the absence of chlorophyll. On the basis of their mode of nutrition, they may be parasite, saprophyte or symbionts.
3. The plant body may be unicellular (*Saccharomyces*) or filamentous (*Mucor*, *Aspergillus*). The filament is known as hypha (plural, hyphae) and its entangled mass is known as mycelium.
4. The hypha may be aseptate i.e., coenocytic (without septa and containing many nuclei) or septate. The septate mycelium in its cell may contain only one (monokaryotic), two (dikaryotic) or more nuclei.
5. The septa between the cell may have different types of pores: micropore, simple pore or dolipore.
6. The cells are surrounded by distinct cell wall, composed of fungal cellulose i.e., chitin; but in some lower fungi, the cell wall is composed of cellulose or glucan.
7. The cells generally contain colourless protoplasm due to absence of chlorophyll, containing nucleus, mitochondria, endoplasmic reticulum, ribosomes, vesicle, microbodies, etc.
8. The cells are haploid, dikaryotic or diploid. The diploid phase is ephemeral (short-lived).
9. In lower fungi, the reproductive cells (zoospores and gametes) may be uni- or biflagellate, having whiplash and/or tinsel type of flagella. But in higher fungi, motile cells never form at any stage.
10. In response to functional need, the fungal mycelia are modified into different types such as: Plectenchyma, Stroma, Rhizomorph, Sclerotium, Hyphal trap, Appresorium, Haustorium, etc.
11. The unicellular fungi, where entire plant body becomes converted into reproductive unit, are known as holocarpic fungi (e.g., *Synchytrium*). However, in many others, only a part of the mycelial plant body is converted into reproductive unit, thus they are called eucarpic fungi (e.g., *Pythium*).
12. They reproduce by three means: Vegetative, asexual and sexual.

(a) Vegetative reproduction takes place by fragmentation (*Mucor*, *Penicillium*), budding (*Saccharomyces*), fission (*Saccharomyces*) etc.,

(b) Asexual reproduction takes place by different types of spores. These are zoospores (*Synchytrium*), conidia (*Aspergillus*), oidia (*Rhizopus*), chlamydospore (*Fusarium*), etc. The spores may be unicellular (*Aspergillus*) or multicellular (*Alternaria*).

13. With the Exception of Deuteromycotina, Sexual Reproduction takes Place by the following Five Processes: Planogametic copulation (*Synchytrium*), Gametangial contact (*Pythium*), Gametangial copulation (*Rhizopus*), Spermatization (*Puccinia*) and Somatogamy (*Agaricus*).

Occurrence of Fungi:

The fungi are cosmopolitan in distribution and occur in all possible habitats. Most of the fungi are terrestrial which grow in soil, on dead and decaying organic material. Some grow on both plants and animals. They can grow on foods like jam, bread, fruits etc. Some members are also found in water — aquatic fungi. They are also present in the air. Thus the fungi are universal in their distribution.

Nutrition in Fungi:

Fungi prefer to grow in darkness, dim light, moist habitat, suitable temperature and where there is availability of living or dead organic matter. They do not synthesize their own food. Thus, all fungi are heterotrophic and holozoic (like animals).

The fungi are chemo-organotrophs (derive energy from oxidation of organic substances) and their nutrition is absorptive (extracellular).

On the basis of their mode of nutrition, the fungi are divided into the following three categories: Due to absence of chlorophyll, they depend on other for food, that is why they may be saprophytes, parasites or symbionts.

A. Parasites:

Fungi which obtain their food material from the living organisms are known as parasites. If it grows on the external surface of the host it is called ectoparasite but if it enters the host and feed within, it is called endoparasite. Intercellular mycelium produce haustoria to absorb the food material from the cells (e.g., *Albugo*) while intracellular mycelium directly absorb the food material from the host cells, (e.g., *Ustilago maydis*).

B. Saprophytes:

Fungi obtaining their food material from the dead organic matter are known as saprophytes.

Parasites and saprophytes may be obligate (they do not grow or reproduce away from the host) or facultative (they can grow on living hosts and also on dead remain of the host).

C. Symbionts:

The living of two (or more) organisms in close association to their mutual benefit is known as symbiosis e.g., mycorrhiza, lichens. The association between the fungus and roots of higher plants is called mycorrhiza (Gr., Mykes = mushroom, rhiza = root). Lichens show a symbiotic association between algae and fungi.

Thallus Organization in Fungi:

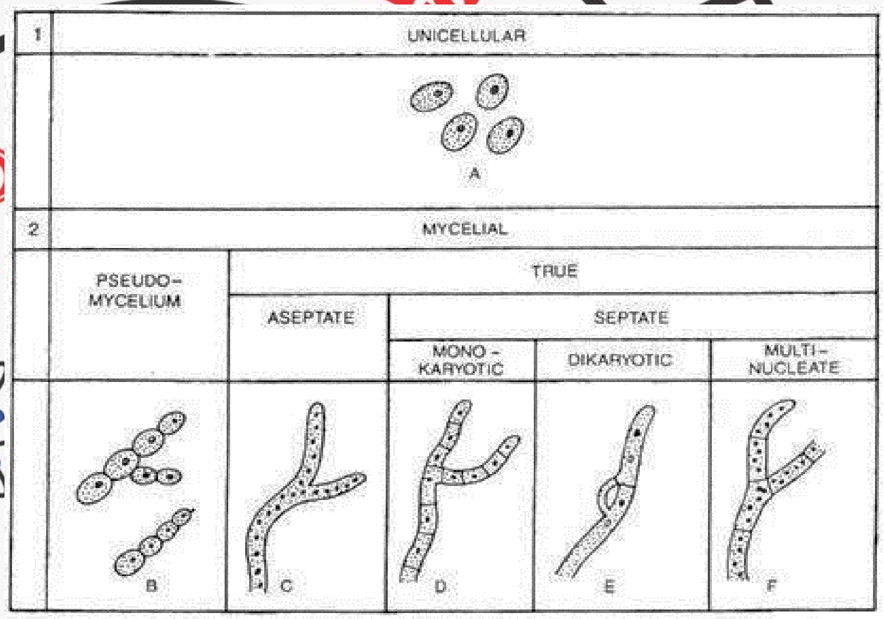


Fig. 4.1 : Different types of thalli in fungi : A-B. *Saccharomyces*, C. *Mucor*, D-E. *Agaricus*, and F. *Penicillium*

1. The fungi body is gametophytic and thalloid (i.e., cannot be differentiated into root, stem and leave). It may be unicellular or filamentous. Some fungi are dimorphic and exist both in unicellular and hyphal form. Majority of the fungi have filament like structures called hyphae (sing. hypha, Gr. hypha = web). A mass of loosely interwoven hyphae is called mycelium.
2. The mycelium may be intercellular (present in between the cells of the host tissue), intracellular (penetrates in the host tissue cells) in parasitic fungi or spreads as loose mass of interwoven hyphae in saprophytic fungi. Mycelium may be systemic (scattered throughout the various parts of the host) or localized (spreads near the point of infection) in parasitic fungi.
3. Hyphae may be septate (divided by septum, L. septum, partition) and it results in the formation of uninucleate or monokaryotic (Fig), bi-nucleate or dikaryotic (Fig) or multi-nucleate (Fig) cells. Some hyphae are not divided by cross walls or septa and are called aseptate. The aseptate and multinucleate mycelium is called coenocytic (Fig).
4. In higher fungi the septa have a small pore in the centre to maintain he protoplasmic continuity between the cells. The septum with a simple centre pore is called simple pore septum (Fig. 5) or surrounded by double membranous structures called septal pore cap or parenthosome on both the sides. It is called dolipore septum. (Fig. 6).
5. Except slime molds the fungal cell is bounded by a cell wall. Fungal cell wall is made of chitin or fungal cellulose. However, in some lower fungi, it is made up of cellulose.
6. Protoplasm consists of every cell organelle except plastids.

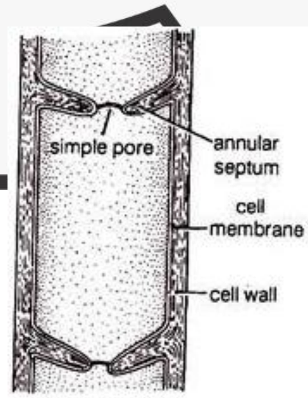


Fig. 5. Fungi : Annular septum with simple pore

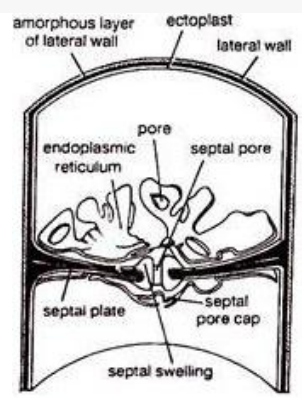


Fig. 6. Fungi : A dolipore septum

7. Vacuoles are present and they are bounded by membranes called tonoplast.
8. Reserve food material is in the form of glycogen and oil drops.
9. Sterols are found.
10. Motile cells are absent in the life cycle of higher fungi. However, the reproductive cells (zoospores and gametes) are motile in lower fungi. The motile cells may be uni- or biflagellate.
11. The flagella (Sing. flagellum; L. flagellum, whip) are of two types—acronematic or whiplash type (sharply pointed tip) and pantonematic or tinsel type (feathery). The internal structure of the flagellum is similar to eukaryotes.

Reproduction in Fungi:

Reproduction is the formation of new individuals having all the characters of typical parents.

In general, a fungus reproduces by three methods:

1. Vegetative reproduction
2. Asexual reproduction.
3. Sexual reproduction.

1. Vegetative Reproduction:

In this type of reproduction, the formation of new thallus takes place from vegetative parts.

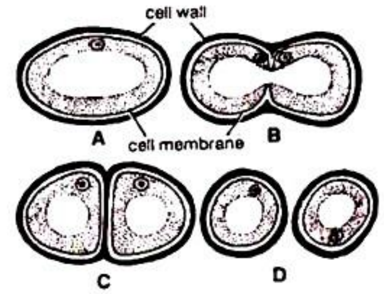


Fig. 13. (A–D). Fungi : Vegetative reproduction by fission

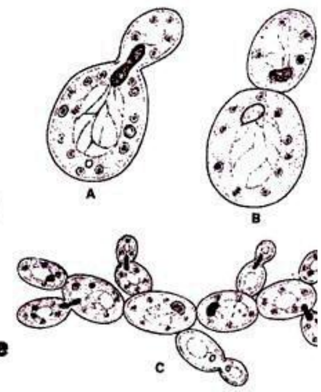


Fig. 14. (A–C). Fungi : Vegetative reproduction (A–B) budding, (C)

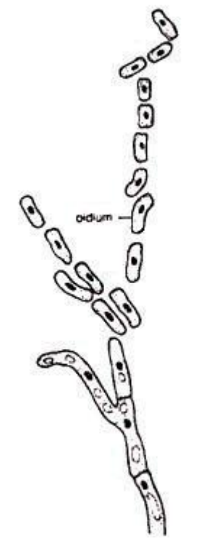


Fig. 15. Fungi : Oidia

The following methods of vegetative reproduction are known in fungi:

(a) Fragmentation:

The mycelium or hyphae break up into a number of small fragments which are capable of developing into a new mycelium under favourable conditions e.g., *Rhizopus*, *Aspergillus*, etc.

(b) Fission:

It is the simple splitting of cell into two daughter cells by a constriction and formation of the cell wall (Fig. 13 A-D) e.g., *Schizo saccharomyces* (commonly known as fission yeast).

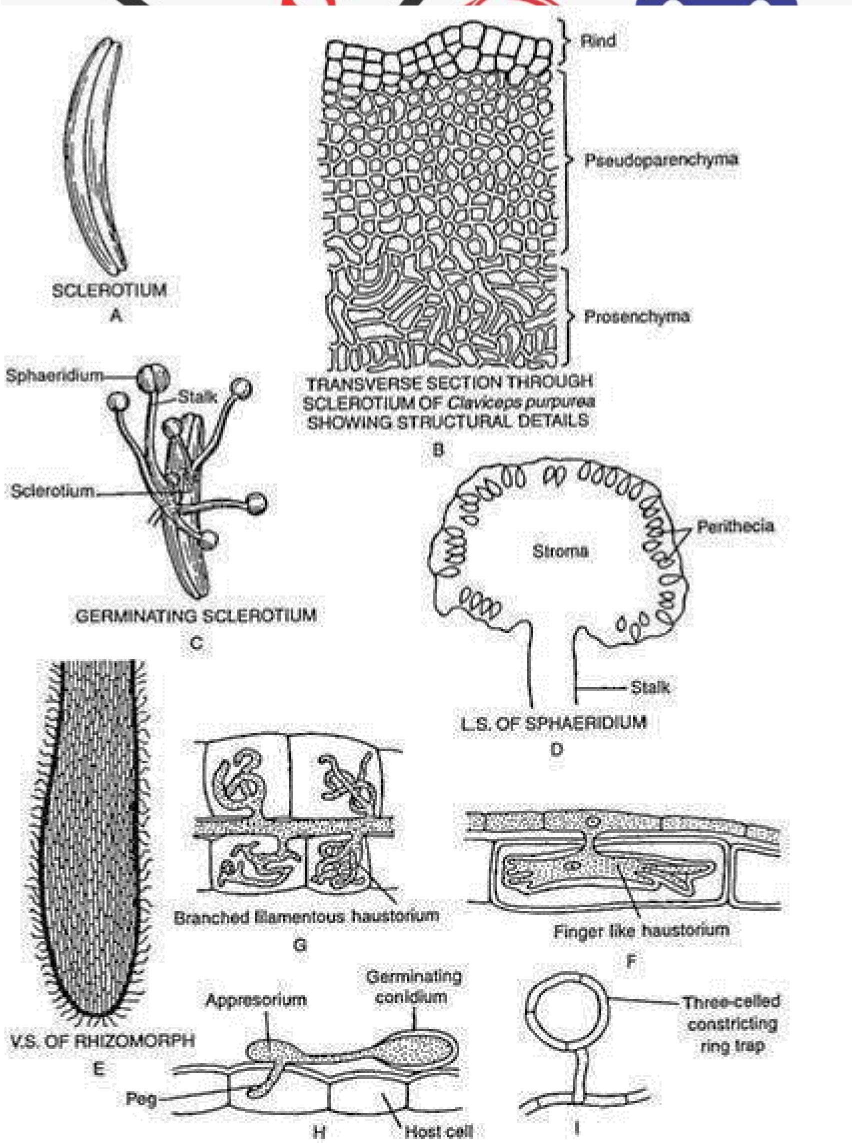
(c) Budding:

It is the formation of small outgrowth (bud) from a parent cell wall which breaks up to form a new individual (Fig. 14 A, B, C) e.g., *Saccharomyces cerevisiae*.

(d) Oidium :

When grow in nutrient medium, the hyphae of some fungi undergo segmentation and form rounded or thin walled cells called oidia. Under favourable conditions each oidium on germination produces a new mycelium e.g., *Mucor*. It is also called arthrospore, it may also behave as a spermatium (Fig. 15).

(e) Chlamydospores:



.6 : Different type of modifications of the hyphal structure : A-D. *Claviceps purpurea*, E. *Armillariella mellea* (= *Armillaria mellea*), F. Haustorium of *Erysiphae graminis* in epidermal cell of oat in longitudinal section, G. Haustoria of *Peronospora calotheca* in stem cells of *Asperula odorata*, H. Appresorium of *Erysiphe graminis tritici* on wheat, and I. Hyphal trap of *Monocresporium*

Some hyphal cells or portions of hypha contract, loose water, round up and become surrounded by a thick wall. These are the resting bodies capable of withdrawing long un-favourable conditions e.g., *Fusarium* etc.

(f) Sclerotia:

These are hard, compact mass of dormant interwoven hyphae. The external hyphae develop hard coat or rind protecting the inner regions from dessication. These are the resting bodies formed by the fungus to pass out the un-favourable.

(g) Rhizomorph:

The rhizomorph mostly develop underground with hyphae very loosely interwoven. The rhizomorph resist un-favourable conditions and remain dormant till favourable conditions come again e.g., *Agaricus*.

2. Asexual Reproduction:

This is the most common method of reproduction in fungi. It takes place by means of spores. It occurs when conditions are usually favourable. Fungi may be polymorphic (producing more than one type of spores) e.g., *Puccinia*. Spores may be unicellular or multicellular, motile or non-motile, may vary in colour, shape and size.

On the basis of origin and development these may be divided into two types:

(A) Accessory spores

(B) Meiospores.

(A) Accessory Spores:

These are never involved in any type of sexual reproduction. The spores may be produced endogenously (produced in sporangia which are present on simple or branched sporangiophores) or exogenously (borne on the tips or sides of hyphae).

Endogenous Spores:

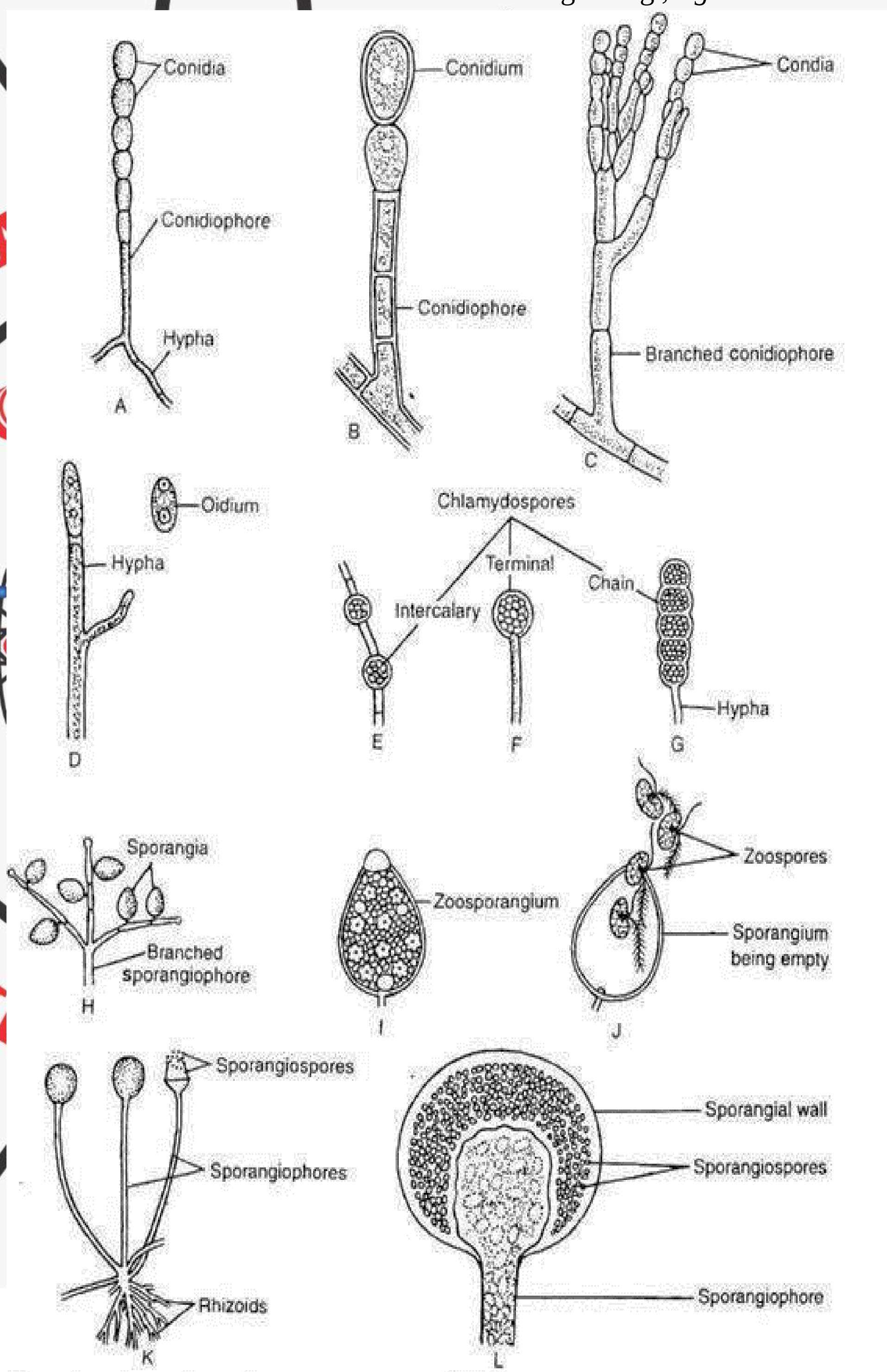
These are also known as sporangiospores. These are two types:

(i) Zoospores:

Are produced in sac-like structures called zoosporangia. Sometimes zoospores are borne in conidiosporangia which are placed either on simple (e.g., *Albugo*) or branched sporangiophores (e.g., *Phytophthora*).

(ii) Aplanospores:

These are non-motile and are produced in sporangia. These spores are found in terrestrial species e.g., *Mucor*. Aplanospores



.8 : Various types of asexual spores of fungi : A. Conidia in chain borne on conidiophore in *Erysiphe*, B. Endoconidium from conidiophore in *Ceratostomella* sp., C. Conidia on branched conidiophore in *Penicillium*, D. Development of oidium, E-G. Chlamydospores, H-J. Development of Zoospores in *Phytophthora*, K. Portion of plant body of *Rhizopus*, showing rhizoids, sporangiophores and sporangia, and L. Portion of sporangiophore of *Rhizopus* with single sporangium may be uninucleate or multinucleate.

Exogenous Spores:

(i) Conidia:

These are non-motile spores and are also known as conidia. They are produced at the tip of vertical hyphae known as conidiophores. Conidiophores may be scattered in mycelium (e.g., *Aspergillus*) or may arise in groups from some specialized structures.

These specialized structures are:

(i) Synnema or Corenium:

Branched or un-branched conidiophores arise very close to each other and are often united below.

(ii) Sporodochium:

Hemispherical or barrel shaped cushion like structure, conidiophores arise from the lower part.

(iii) Acervulus:

Saucer shaped, flat open bed of conidiophores.

(iv) Pustules:

A mass of fungal spores and hyphae bearing them is called a pustule. Sporophores are formed below the surface of host plant and are limited in outline. Spores vary in shape, size and structure e.g., *Puccinia* (Fig. 17 A, B).

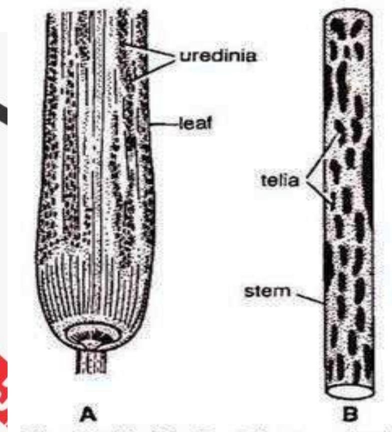


Fig. 17. (A, B). Pustule on wheat plant :

(ii) Meiospores: These are the true spores of asexual reproduction. These spores are formed after meiosis or reduction division of the diploid nuclei. Thus, they are haploid to give rise to mycelium of primary nature.

These are of two types:

(A) Ascospores:

They are produced within special sac like structures called the asci (singular Ascus). They are endogenous in origin. The number of ascospores produced within each ascus is typically eight. (Fig. 18)

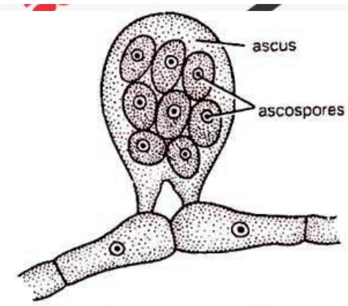


Fig. 18. Fungi : Ascospores in ascus

(B) Basidiospores:

These are borne outside on the club shaped structures called basidia, resulting from karyogamy and meiosis. Thus, they are exogenous in origin. (Fig. 19).

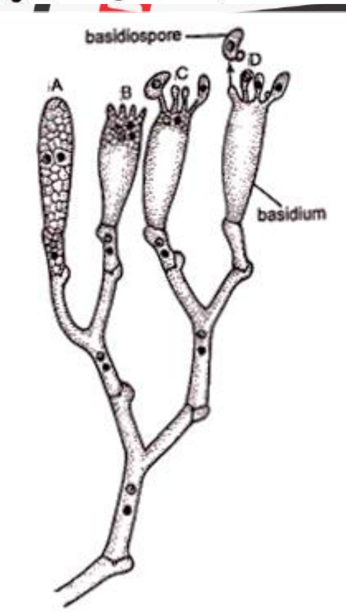


Fig. 19. Fungi : (A–D) Basidia with basidiospores

3. Sexual Reproduction:

Sexual reproduction in fungi consists of three distinct phases:

(1) Plasmogamy:

In this process only the protoplasm of the two fusing sex cells or gametes fuse and the nuclei of the fusing bodies come close to each other.

(2) Karyogamy:

Plasmogamy is followed by the fusion of the nuclei resulting in the formation of diploid zygote nucleus.

(3) Meiosis:

Karyogamy is followed by meiosis or reduction division which reduces the number of chromosomes to haploid.

There are following three methods of sexual reproduction:

A. Amphimixis.
B. Automixis.
C. Somatogamy.

(A) Amphimixis:

In this method the fusing sex cells or gametes copulate to form a new entity.

This is of following types:

(i) Planogametic Copulation or Merogamy: This process involves the fusion of two naked gametes, one or both of which are motile. Motile gametes are known as planogametes. After fusion they form the zygote or oospore.

It is of the following types:

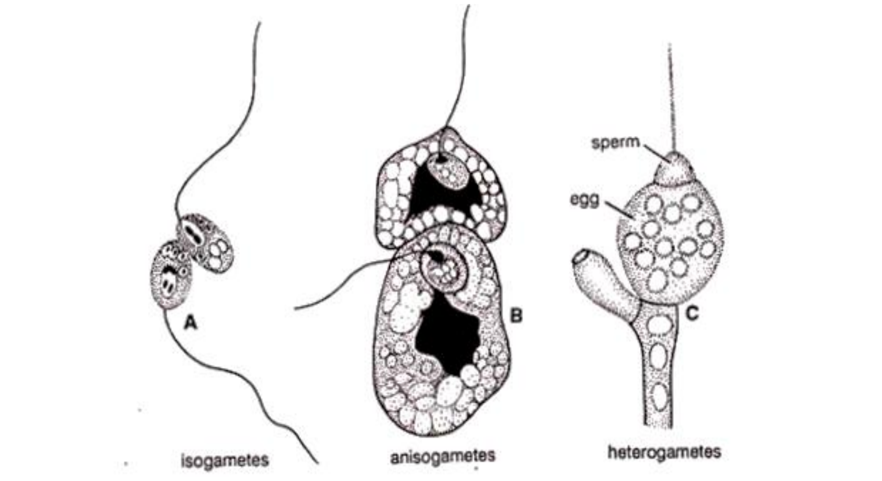


Fig. 20. (A–C). Fungi : Sexual reproduction. (A) Isogamous, (B) Anisogamous, (C) Oogamous

(a) Isogamous:
Gametes are isoplanogametes. Motile gametes, Presumably of opposite sex are indistinguishable morphologically e.g, *Synchytrium*. (fig. 20A).
(b) Anisogamous:
Motile gametes are similar in shape but differ in size e.g., *Allomyces* (Fig. 20 B).
(c) Oogamous:
Male gamete (antherozoid) is motile and female gamete (egg) is non-motile e.g., *Monoblepharella* (Fig. 20 C).

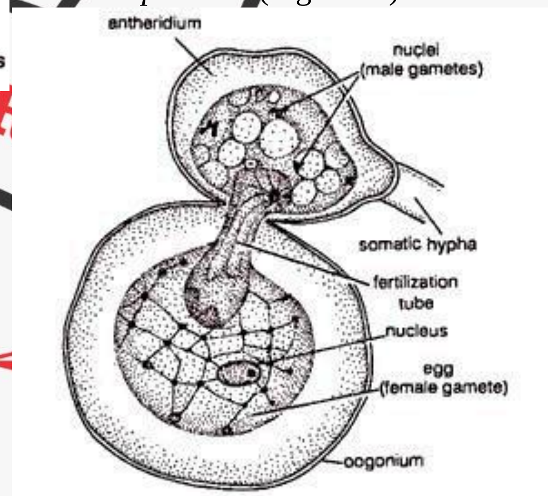


Fig. 21. Fungi : Sexual reproduction. Gametangial contact

(ii) Gametangial Contact:
In this method gametes are never released. Two gametangia of opposite sex come in contact and one or more gametic nuclei migrate from the male gametangium to the female. The gametangia are non-motile and the male contents are transferred either through a pore or through a fertilization tube e.g., *Albugo* (Fig. 21).

(iii) Gametangial Copulation:
This method involves the fusion of the entire contents of the two connecting gametangia. This takes place by the dissolution of the connecting walls of the two gametangia e.g., *Rhizopus*, *Saccharomyces*. (Fig. 22 A, B).

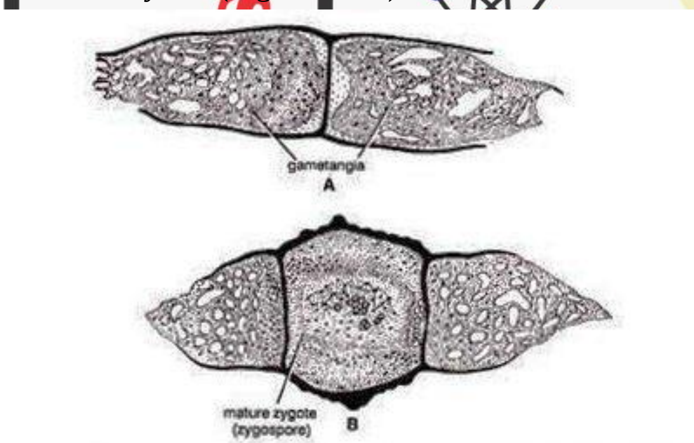


Fig. 22 (A–B). Fungi : Sexual reproduction. (A) Gametangia. (B) Gametangial copulation

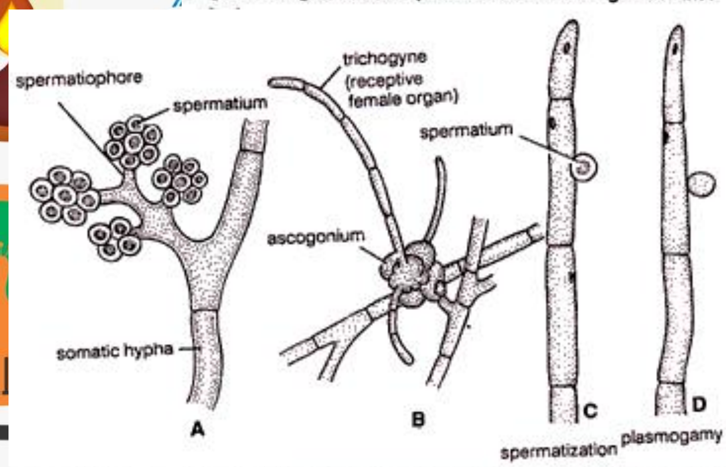


Fig. 23 (A–D). Fungi : (A) Spermatia, (B) Receptive hypha, (C) Spermatization, (D) Plasmogamy

(iv) Spermatization:
Some higher fungi reproduce sexually by this method. Here the male structures are minute uninucleate cells known as spermatia. They are carried away by insects, wind or water to a reduced female gametangium, which may be a specialized hypha called receptive hypha.
A pore develops at the point of contact and contents of the spermatium pass into the female organ e.g., *Puccinia*. (Fig. 23 A-D). Plasmogamy by the union of a spermatium with a receptive structure is called spermatization.
(v) Hologamy:
Two mature vegetative cells function as gametangia, fuse in pairs and form fusion cell. Plasmogamy, karyogamy result in the formation of diploid nucleus, called zygote. It directly behaves as an ascus mother cell e.g., *Schizo saccharomyces*.
(B) Automixis:

In this method copulation takes place between two closely related sexual cells or nuclei (self-fertilization) e.g., *Ascobolous magnificius*.

(C) Somatogamy:

In this method fusion takes place between two cells of somatic hypha. Sex organs are completely absent. (Fig. 24).

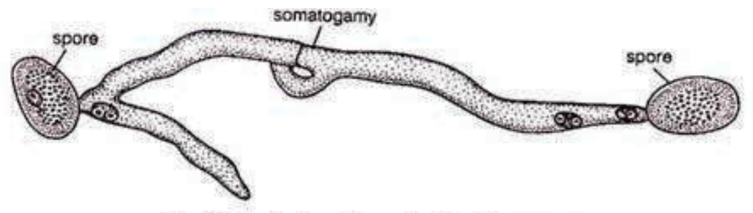


Fig. 24. Fungi : Sexual reproduction. Somatogamy

Classification of Fungi:

Taxonomy has a dual purpose—first to name an organism according to some internationally accepted system and then to indicate the relationship of the particular organism with other living organisms. As our knowledge increases, the classification changes.

Even the name of organisms do not always remain stable because as we learn new facts about them, it often becomes necessary to alter our concept of their relationship which in turn demands reclassification and a change of name. The classification of fungi is still in a state of flux. A stable or ideal scheme is yet to be proposed.

In accordance with the recommendations of the committee on International rules of Botanical Nomenclature:

(a) The name of divisions of fungi should end in—mycota.
(b) The name of subdivisions should end in—mycotina.
(c) The name of classes should end in—mycetes.
(d) The name of subclasses should end in—mycetideae.
(e) The name of orders should end in—ales.
(f) The name of families should end in a suffix—aceae.

Genera and species have no standard endings. The name of an organism is binomial. It is composed to parts—the first is noun designating the genus in which the organism has been classified, and the second is often an adjective describing the noun which denotes the species. The first letter of each generic name is always a capital.

Criteria Used in Fungal Classification:

Linnaeus (1753), Persoon (1801), De Bary (1866), Saccardo (1899), Gwynne-Vaughan and Barnes(1926), classified the fungi on the basis of their morphology. Later on Tippo (1942), Bessey (1950), Gaumanr and Dodge (1952), Martin (1961), Alexopoulos (1962) and Ainsworth (1966, 73), CJ Alexopoulos, CW Mims (1979), CJ Alexopoulos, CW Mims and M Blackwell (1996) classified the fungi on the basis of following important characters:

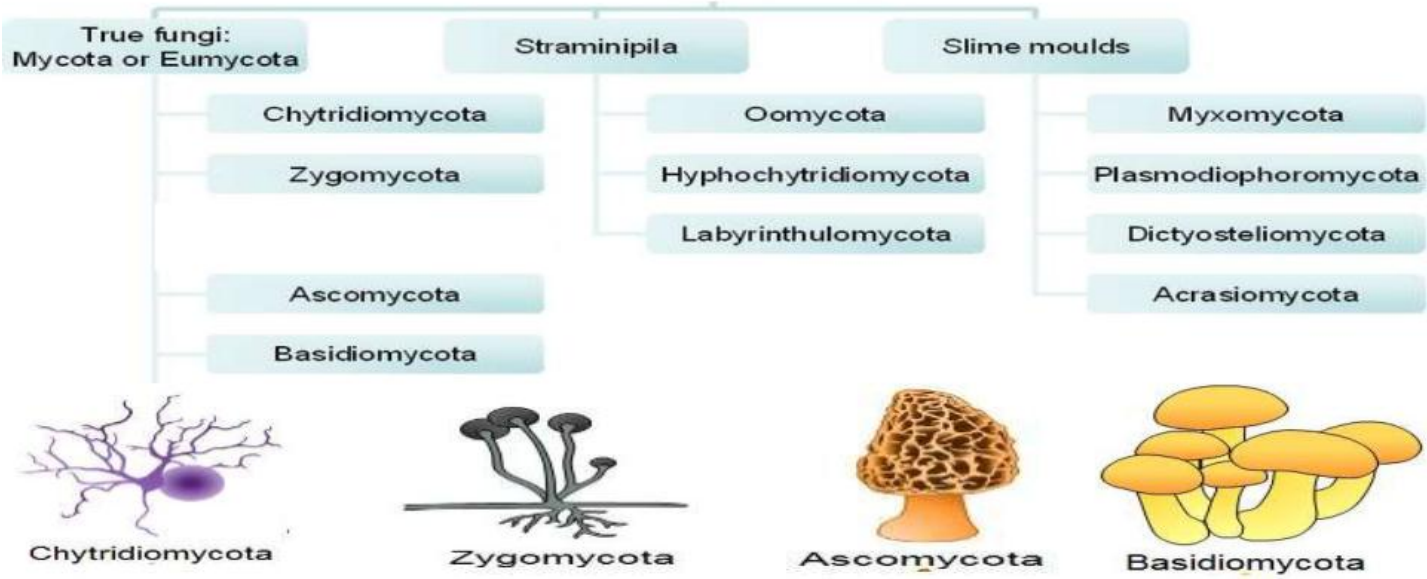
1. Thallus organization and structure.
2. Colour.
3. Shape.
4. Food habits.
5. Cell wall composition.
6. Separation of spores.
7. Flagellation.
8. Sexual reproduction and asexual reproduction.
9. Life cycle.

This criterion is called Classical Criterion. However, Tyrell and Hall (1969) classified fungi on basis of cell wall chemistry.

Now-a-days fungi can be classified by using the following biochemical criteria:

1. Call wall composition.
2. Type of amino acids.
3. Composition of DNA base.
4. Proteins.
5. Biosynthetic pathways. This criterion is called Potential Criteria.

Outline of classification system proposed by CJ Alexopoulos, CW Mims and M Blackwell (1996)



STRUCTURE, REPRODUCTION AND LIFE HISTORY OF *Albugo*

CLASSIFICATION OF *Albugo (Cystopus)*

Division: Mycota
Class: Phycomycetes
Order: Peronosporales
Family: Albuginaceae
Genus: *Albugo* (derived from a Latin word means white)

1. Habit and Habitat of *Albugo*:

Albugo Or Cystopus (derived from a Latin word means white), the only genus of family Albuginaceae is represented by more than 25 species. It is an obligate parasite distributed all over the world. In India about 18 species of *Albugo* have been reported which attacks mostly crucifers like turnip, mustard, radish, cabbage, cauliflower etc.

2. Symptoms of *Albugo*:

The disease caused by *Albugo* is commonly known as white rust because it appears in the form of shiny, white, smooth irregular patches (pustules) or blisters on the leaves, stems and other aerial parts of the plant. The pustules are initially formed on the lower surface of the leaf but in several cases, they may be present on both the surfaces.

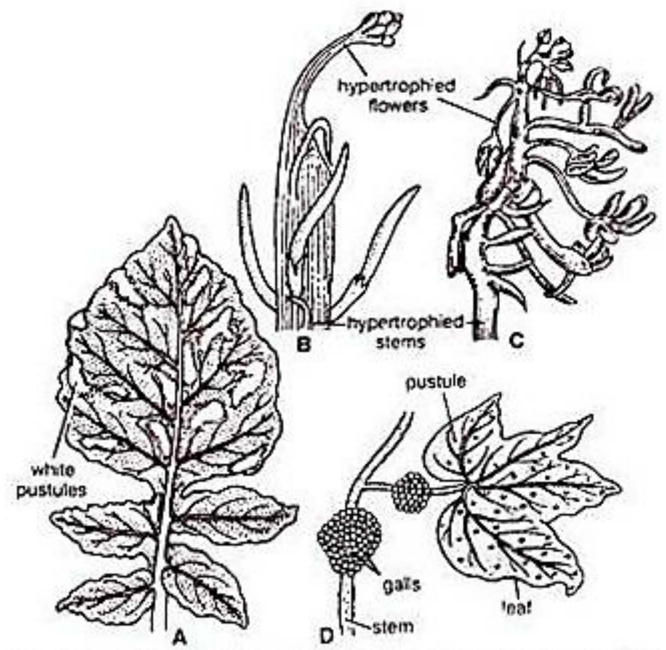


Fig. 1. (A–D). *Albugo*: Symptoms. (A) Infected radish leaf showing pustules; (B–C) Hypertrophied flowers and stem; (D) Galls on stem

3. Vegetative Structure of *Albugo*:

Thallus is eucarpic and mycelial. Hyphae are endophytic, intercellular, hyaline, coenocytic, aseptate, and profusely branched. Cell wall is composed of fungal cellulose. Some mycelium is intracellular in the form of knob-like haustoria for the absorption of food material from the host cells.

4. Reproduction in *Albugo*:

The fungus reproduces both by asexual and sexual methods.

Asexual Reproduction:

The asexual reproduction takes place by conidia, condiosporangia or zoosporangia. They are produced on the sporangiophores. After attaining a certain age of maturity, it produces a dense mat like growth just beneath the epidermis of the host. These hyphae at right angles to the epidermis produces many short, thick walled, un-branched and club or clavate shaped sporangiophores or conidiophores. They form a solid, palisade like layer beneath the epidermis. After reaching a certain stage of maturity, the apical portion of sporangiophore gets swollen and is ready is cut off a sporangium or conidium.

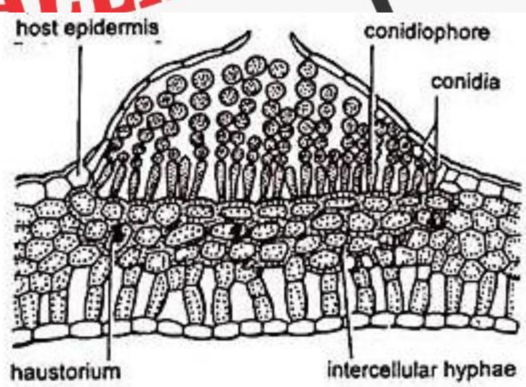


Fig. 3. *Albugo*: Asexual reproduction V.S. of *Brassica* leaf passing through infected portion

The sporangia are produced at the tip by constriction method. A Deeping constriction appears below the swollen end and results in the formation of first sporangium. A second sporangium is similarly formed from the tip just beneath the previous one. This process is repeated several times. The new nuclei migrate from mycelium to cytoplasm and are used in the formation of another sporangium or conidium. Thus, a long chain of sporangia or conidia is formed above each sporangiophore in basipetal succession. (youngest at the base and oldest at the tip).

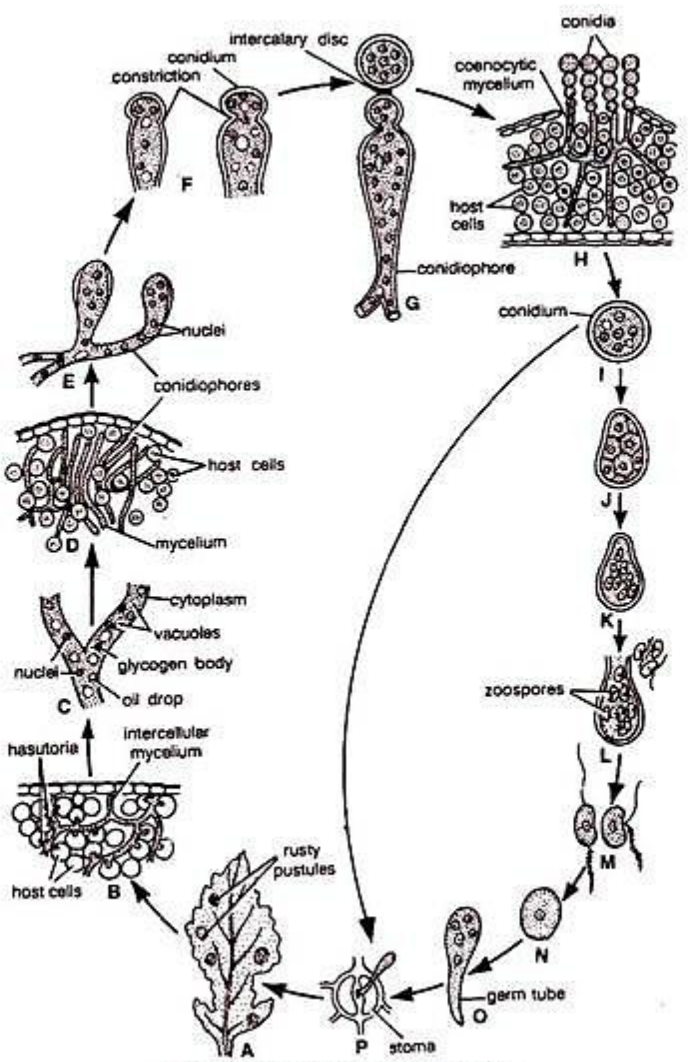


Fig. 2. (A–D). *Albugo* : A sexual reproduction

The sporangia or conidia are spherical, smooth, double walled, hyaline and multinucleate structures. The walls between them fuse to form a gelatinous disc-like structure called disjunctor or separation disc or intercalary disc. It tends to hold the sporangia together. The continued growth and production of sporangia exerts a pressure upon the enveloping epidermis. Which is firstly raised up but finally ruptured exposing the underlying sorus containing white powdery dust of multinucleate sporangia or conidia.

The separation discs are dissolved by water, and the sporangia are set free. They are blown away in the air by wind or washed away by rain water under suitable environmental conditions and falling on a suitable host, sporangia germinates with in 2 or 3 hours. The sporangia germinate directly or indirectly depending on temperature conditions.

At high temperature and comparatively dry conditions, the sporangium germinates directly. It gives rise to a new mycelium inside the host.

In the presence of moisture and low temperature (10°C) the sporangium germinates indirectly i.e., it behaves like zoosporangium and produces zoospores.

Zoospore:

The zoospores are uninucleate, slightly concavo-convex and biflagellate. After swimming for some time in water, they settle down on the host. They retract their flagella, secrete a wall and undergo a period of encystment. On germination, they put out a short germ tube which enters the host through stomata or again infects the healthy plants.

Sexual Reproduction:

The sexual reproduction is highly oogamous type. The antheridium and oogonium develops deeper in the host tissue in close association within the intercellular spaces. The antheridium and oogonium are formed near each other on hyphal branches. They are terminal in position.

Antheridium:

It is elongated and club shaped structure. It is multinucleate (6-12 nuclei) but only one nucleus remains functional at the time of fertilization

Oogonium:

It is spherical and multinucleate containing as many as 65 to 115 nuclei. All nuclei are evenly distributed throughout the cytoplasm (Fig. 4 A-C). As the oogonium reaches towards the maturity the contents of the oogonium get organised into an outer peripheral region of periplasm and the inner dense central region of ooplasm or oosphere or the egg (Fig. 4 D-F). The ooplasm and periplasm are separated by a plasma membrane. However, at the time of maturity, all nuclei disintegrate, except single functional nucleus.

Fertilization:

The functional female nucleus attracted towards it and becomes attached to a point near it. The oogonium develops a papilla (Fig. 4 G) like out growth at the point of contact with the antheridium. This is called as receptive papilla. Soon it disappears, and the antheridium develops a fertilization tube (Fig. 4 H, I).

It penetrates through receptive papilla, oogonial wall and periplasm and finally reaches upto the ooplasm. It carries a single male nucleus. Its tip ruptures to discharge the male nucleus near the female nucleus. Ultimately the male nucleus fuses with the female nucleus (karyogamy) (Fig. 4 J).

Oospore:

The oospore along with the fused nucleus is called oospore which is uninucleate now.

Germination of oospore:

With the secretion of the wall, the zygotic nucleus divides repeatedly to form about 32 nuclei. The first division is meiotic. At this stage the oospore undergoes a long period of rest until unfavorable conditions are over. Meanwhile its host tissues disintegrate leaving the oospore free. After a long period of rest the oospore germinates. Its nuclei divide mitotically and large number of nuclei are produced. A small amount of cytoplasm gathers around each nucleus. Protoplasm undergoes segmentation and each segment later on rounds up and metamorphoses into a zoomeiospore or zoospore (Fig. 4 O). The exospore is ruptured and the endospore comes out as a thin vesicle (Fig. 4 M).

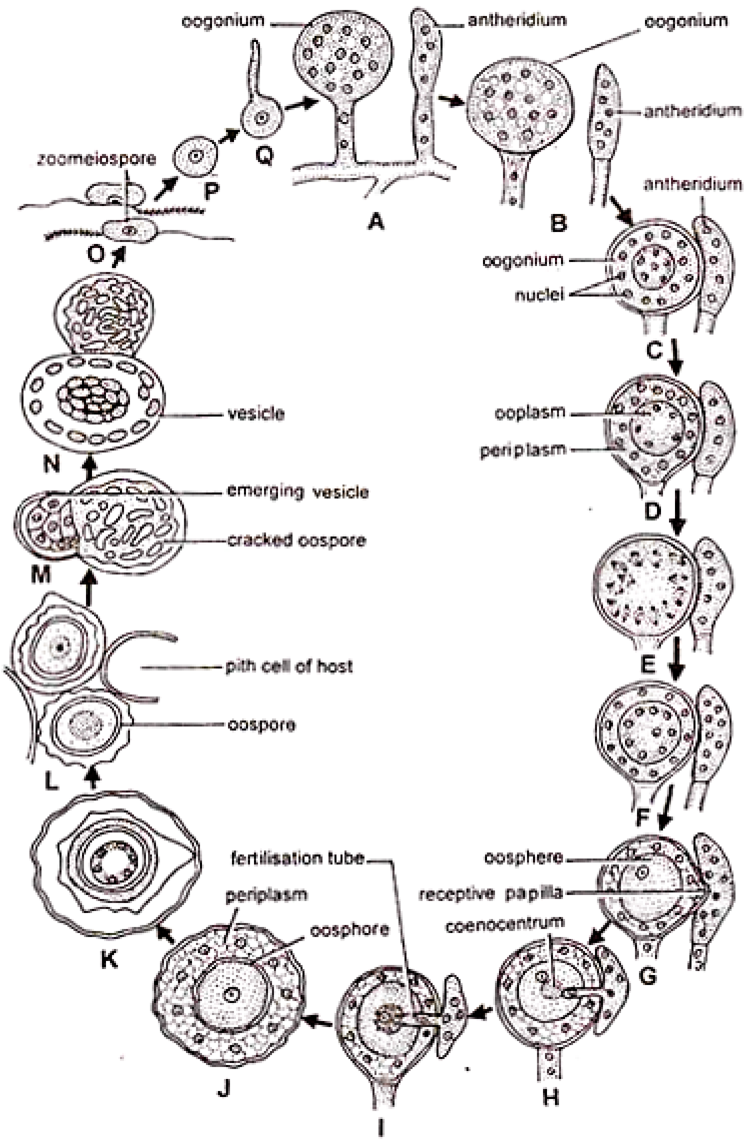


Fig. 4. (A–Q). *Albugo* : Sexual reproduction

The zoospores move out into the thin vesicle which soon perishes to liberate the zoospores.

Germination of Zoospore:

The zoospores are reniform (kidney shaped) and biflagellate. The zoospores after swimming for sometime encyst and germinate by a germ tube which reinfects the host plant (Fig. 4 O, P, Q).

6. Control Measures of *Albugo*:

(i) Growing resistant varieties.

(ii) Eradication of infected plant and their complete destruction.

(iii) Rotation of crucifers plants with non-cruciferous plants.

(iv) Spraying the fungicides like lime, Sulphur etc.

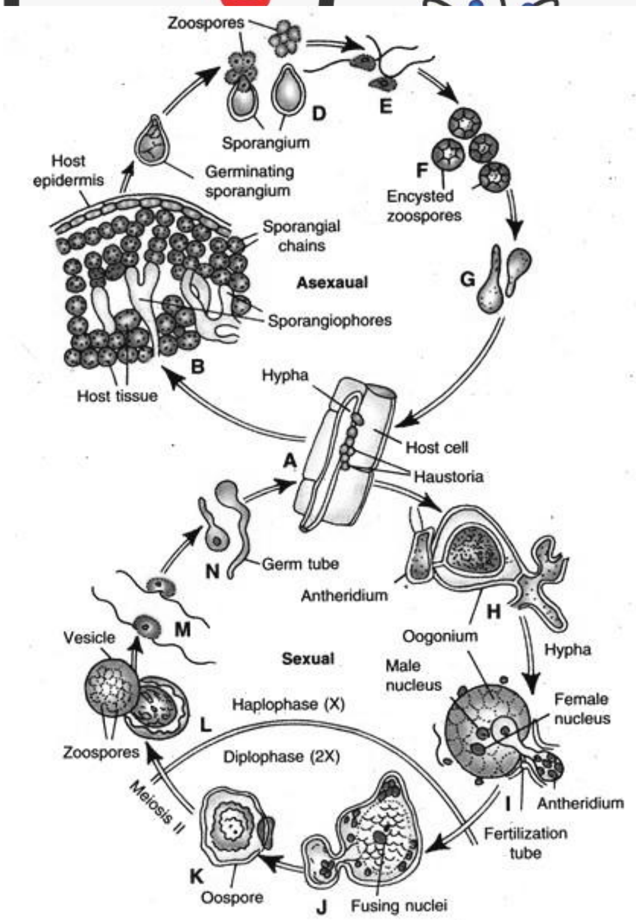


Fig. 6.61. Diagrammatic life cycle of *Albugo candida.*

STRUCTURE, REPRODUCTION AND LIFE HISTORY OF *Peziza*

CLASSIFICATION OF *Peziza* (Cup Fungus)

Class: Ascomycetes
Order: Pezizales
Family: Pezizaceae
Genus: *Peziza*

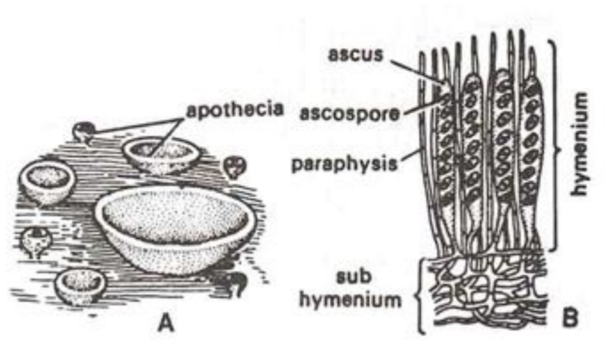


Fig. 89. Peziza. A, Some fruiting bodies; B, A few asci, ascospores and paraphyses.

INTRODUCTION:

Peziza genus includes about 160 species, of these 13 species have been recorded from India. Some common species found are *Peziza pustulata, P. badia, P. catinus, P. vesiculosa.* It is a common saprophyte growing on rich humus soils, well fertilized gardens, mature piles, decaying woods, on ground in decicuous forests and open places. Sometimes it becomes coprophilous (grows on cow dung).

Mycelium of *Peziza*:

It is well developed, frequently perennial and consists of a dense network of branched, septate hyphae with uninucleate cells except in fructifications. The hyphae are hidden from view as they ramify within the substratum. They form a complex system which extracts nourishment from the substratum. The fruiting bodies are above ground.

Asexual Reproduction of *Peziza:*

1. Asexual reproduction takes place by conidia and chlamydospores.
2. The conidia are formed exogenously at the tip of conidiophores.
3. Conidia germinate to form the new mycelium.
4. Some intercalary, thick-walled cells are formed in the mycelium. These are chlamydospores. On germination, they form new mycelium.

Sexual Reproduction of *Peziza*:

1. Sexual Reproduction takes place by means of antheridium and ascogonium.
2. Sexual fusion results into a bright coloured, cup-shaped, large and sessile apothecial type of fruiting body (Figs. 89, 90).
3. In vertical section of an apothecium, following structures are visible (Fig 90).
(a) Apothecium consists of mycelium with a basal hypothecium.
(b) Hymenium region consists of many fertile asci and sterile paraphyses.
(c) Sub-hymenium is made up of pseudo- parenchymatous hyphae which later on form the peridium of the cup.
(d) In each ascus are present eight uninucleate ascospores which form the new mycelium on germination.

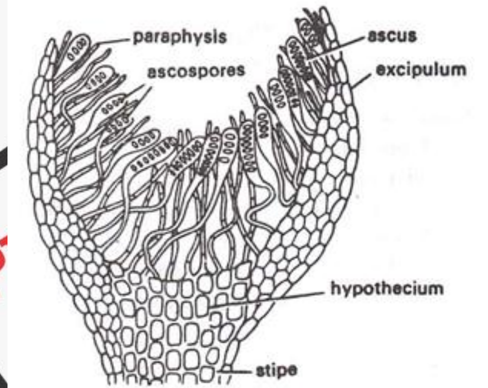


Fig. 90. Peziza. V.S. of an apothecium.

LICHENS

Definition of Lichens:

A lichen can be defined as they are a small group of plants of composite nature structurally-organized entity consisting of the permanent symbiotic association two dissimilar organisms such as fungus (mycobiont, mykes-fungus; bios-life) and an alga (phycobiont, phycos-alga; bios-life).

Introduction:

Theophrastus used the term 'lichen', a word of Greek origin, to signify a superficial growth on the bark of olive trees. About 400 genera and more than 17,000 species of lichens have been reported so far, and now it has become a separate branch of Botany with the name Lichenology.

The fungal partner occupies the major portion of the thallus and produces its own reproductive structures. The algal partner manufactures the food through photosynthesis which probably diffuses out and is absorbed by the fungal partner.

Most of the fungal members in the lichens belong to class Ascomycetes (Sac fungi), except a few of Basidiomycetes (Club fungi). The algal members belong to Chlorophyceae (Green algae- *Cystopus*, *Cladophora*, *Trebouxia*, *Trentepohlia*, *Coccomyxa* etc.), Xanthophyceae (*Heterococcus*) and also Cyanobacteria (Blue green algae- *Nostoc*, *Scytonema* etc.)

Habitat and distribution:

Found in different regions of the world (Cosmopolitan). They grow luxuriantly in the forest areas with free or less pollution, with abundant moisture, moderate temperature and direct sunlight.

They can withstand extremes of climate (Cold, heat and drought) and thus grow in most inhospitable and uninhabited places like barren rocks, cooled volcanic lava, icy tundra or alpines, sand dunes, roofs, walls, window panes, tree barks, leaves, dead logs etc.,

They do not grow in the highly polluted regions like Industrial areas. They are perennial with very slow growth and sensitive to sulphur dioxide. Hence cannot be seen in cities.

Some species like *Cladonia rangiferina* (reindeer moss) grows in the extremely cold condition of Arctic tundras and Antarctic regions. In India, they grow abundantly in Eastern Himalayan regions.

Habit of Lichens:

The plant body is thalloid with different shapes, variously lobed and flat or sometimes cylindrical or erect structures, of various colours. They are usually grey or greyish green in colour, but some are red, yellow, orange or brown in colour.

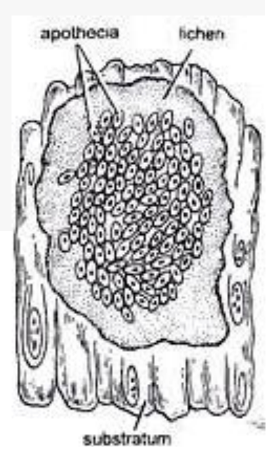
A. External Structure of Thallus:

Based on the external morphology, general growth and nature of attachment, three main types or forms of lichens (crustose, foliose and fruticose) have been recognised. Later, based on detailed structures,

Hawksworth and Hill (1984) categorised the lichens into five main types or forms:

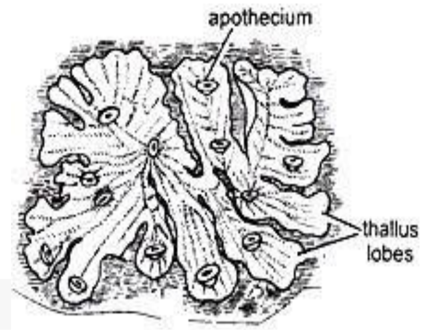
1. Leprose: This is the simplest type, where the fungal mycelium envelops either single or small cluster of algal cells. The algal cell does not envelop all over by fungal hyphae. The lichen appears as powdery mass on the substratum, called leprose, e.g., *Lepraria incana*.

2. Crustose: These are encrusting lichens where thallus is inconspicuous, flat and appears as a thin layer or crust on substratum like barks, stones, rocks etc. They are very closely adhered or wholly or partially embedded in the substratum. It is very difficult to separate them from their substratum. Thallus of majority of this lichens has more or less leathery texture and is internally differentiated with the algal component always restricted to a definite portion of the thallus. Some lichens have gelatinous thallus, in which alga and fungus are uniformly distributed through a gelatinous matrix. Fruiting bodies are present on the upper surface e.g., *Graphis*, *Lecanora*, *Lecidia* etc.



CRUSTOSE LICHEN Eg. *Graphis*

3. Foliose: These are leaf-like lichens, where thallus is flat, horizontally spreading (broad), well-branched and with lobes. Some parts of the thallus are attached with the substratum by means of separate branched or unbranched hyphae or several parallel hyphae closely adhered to each other to form strands called the rhizines, developed from the lower surface (Fig. 4.112C), e.g., *Parmelia*, *Physcia*, *Peltigera* etc.

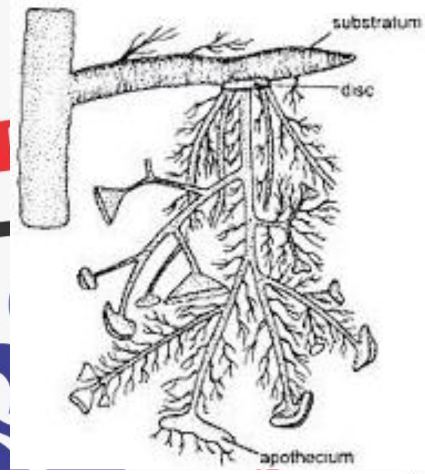


FOLIOSE LICHEN Eg. *Parmelia*

4. Fruticose (Frutex, Shrub): These are shrubby lichens, where thalli are well developed, cylindrical, branched, shrub-like (Fig. 4.112D), either grow erect (*Cladonia*) or (pendant) hang from the substratum (*Usnea*). They are attached to the substratum by a basal disc e.g., *Letharia*, *Alectonia* etc.

5. Filamentous: In this type, algal members are filamentous and well-developed. The algal filaments remain ensheathed or covered by only a few fungal hyphae. Here algal member remains as dominant partner, called filamentous type, e.g., *Racodium*, *Ephebe*, *Cystocoleus* etc.).

6. **Squamulose:** consisting of small scale-like structures or lobes and lacking a lower cortex.



FRUTICOSE LICHEN Eg. *Usnea*

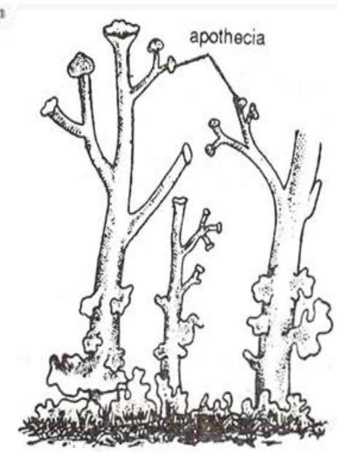


Fig. 120. Cladonia sp. A fruticose lichen.

B. Internal Structure of Thallus:

Based on the distribution of algal member inside the thallus, the lichens are divided into two types. Homoisomerous or Homomerous and Heteromerous.

1. Homoisomerous: Here the fungal hyphae and the algal cells are more or less uniformly distributed throughout the thallus. The algal members belong to Cyanophyta. This type of orientation is found in crustose lichens. Both the partners intermingle and form thin outer protective layer (Fig. 4.11 3A), e.g., *Leptogium*, *Collema* etc.

2. Heteromerous: Here the thallus is differentiated into four distinct layers upper cortex, algal zone, medulla, and lower cortex. The algal members are restricted in the algal zone only. This type of orientation is found in foliose and fruticose lichens (Fig. 4.113B) e.g., *Physcia*, *Parmelia* etc.

The detailed internal structure of this type is:

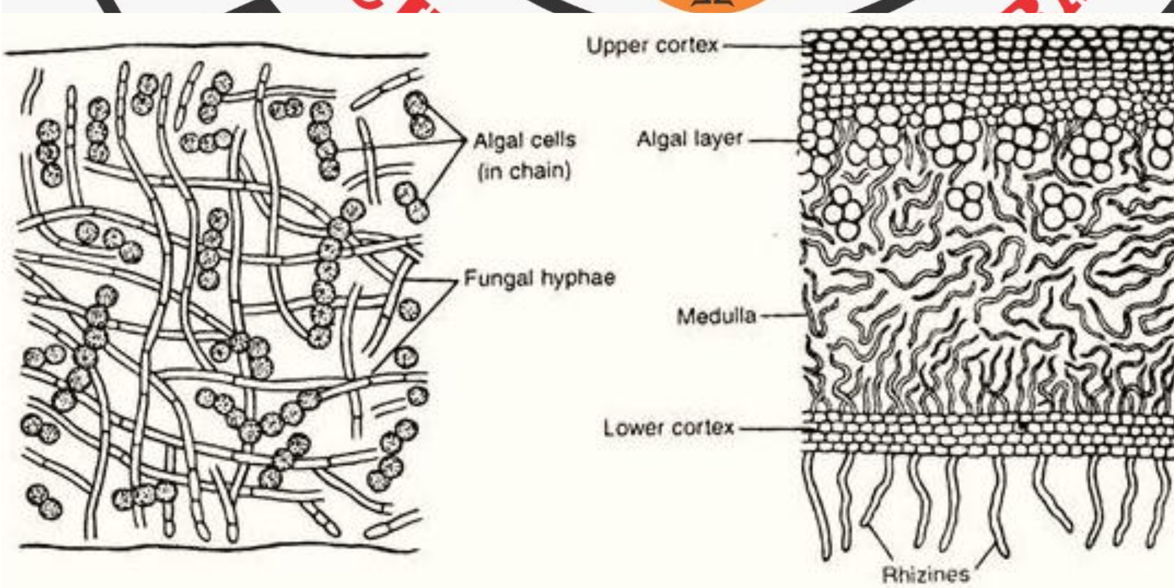


Fig. 4.113 : Internal structure of lichen thallus : A. Homoisomerous thallus, and B. Heteromerous thallus

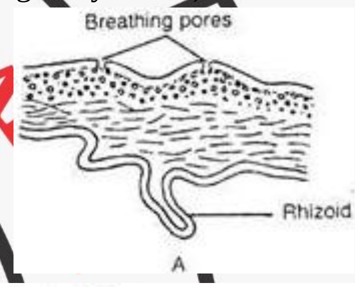
(a) Upper Cortex: It is a thick, outermost protective covering, made up of compactly arranged interwoven fungal hyphae located at right angle to the surface of the fruit body. Usually there is no intercellular space between the hyphae, but if present, these are filled with gelatinous substances.

(b) Algal Zone: The algal zone occurs just below the upper cortex. The algal cells are entangled by the loosely interwoven fungal hyphae. The common algal members may belong to Cyanophyta like *Gloeocapsa* (unicellular); *Nostoc*, *Rivularia* (filamentous) etc. or to Chlorophyta like *Chlorella*, *Cystococcus*, *Pleurococcus* etc. This layer is either continuous or may break into patches and serve the function of photosynthesis.

(c) Medulla: The medulla is situated just below the algal zone, comprised of loosely interwoven thick-walled fungal hyphae with large space between them.

(d) Lower Cortex: It is the lowermost layer of the thallus. This layer is composed of compactly arranged hyphae, which may arrange perpendicular or parallel to the surface of the thallus. Some of the hyphae in the lower surface may extend downwards and penetrate the substratum which help in anchorage, known as rhizines.

The internal structure of *Usnea*, a fruticose lichen, shows different types of orientation. Being cylindrical in cross-section, the layers from outside are cortex, medulla (composed of algal cell and fungal mycelium) and central chondroid axis (composed of compactly arranged fungal mycelia).



C. Specialized Structures of Thallus:

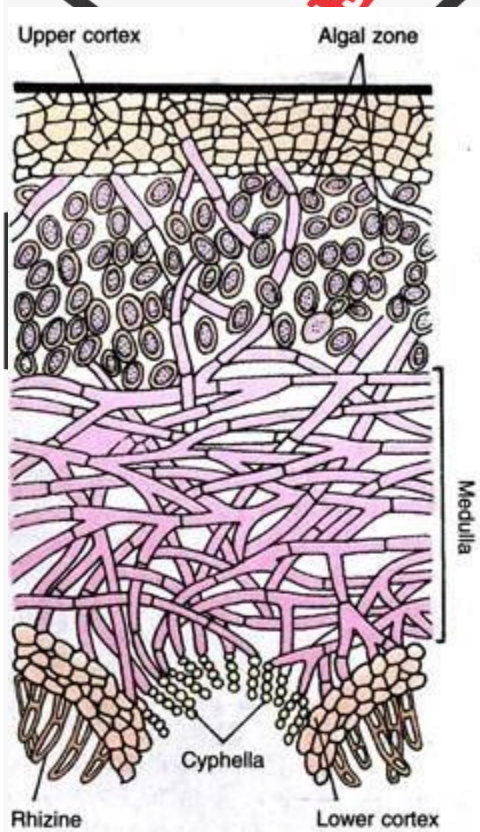


Fig. 20.4. *Lichens.* V. S. thallus passing through a *Cyphella.*

1. Breathing Pore: In some foliose lichen (e.g., *Parmelia*), the upper cortex is interrupted by some opening, called breathing pores, which help in gaseous exchange.

2. Cyphellae: On the lower cortex of some foliose lichen (e.g., *Sticta*) small depressions develop, which appears as cup-like white spots, known as Cyphellae (Fig. 20.4). Sometimes the pits that formed without any definite border are called Pseudocyphellae. Both the structures help in aeration.

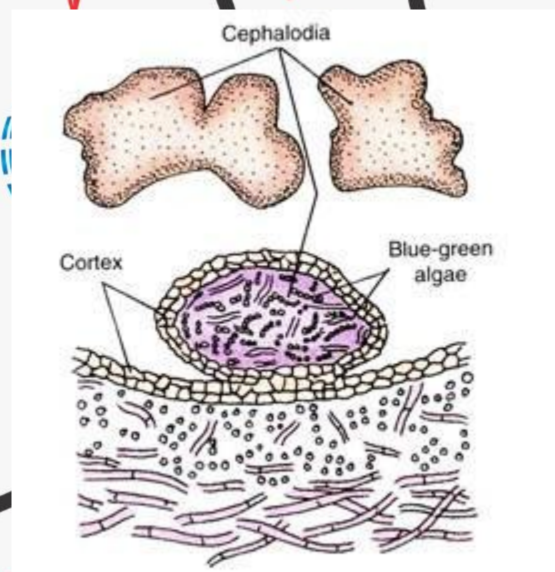


Fig. 20.5 (A–B). *Lichens.* A. Cephalodia in surface view; B. V. S. Thallus passing through the Cephalolium.

3. Cephalodium: These are small warty outgrowths on the upper surface of the thallus (Fig. 20.5 A-B). They contain fungal hyphae of the same type as the mother thallus, but the algal elements are always different. They probably help in retaining the moisture. In *Nepromа*, the Cephalodia are endotrophic.

CLASSIFICATION OF LICHENS:

Depending on the growing region, the lichens are grouped as:

1. Corticoles: Growing on bark of trees, mainly in the sub-tropical and tropical regions.

2. Saxicoles: Growing on rocks, in cold climate.

3. Terricoles: Growing on soil, in hot climate, with sufficient rain and dry summer.

Natural system of classification is not available for lichens. **Based on the structure of fruit bodies of fungal partners, Zahlbruckner (1926) classified lichens into two main groups:**

1. Ascolichens: The fungal member belongs to Ascomycotina.

Based on the structure of the fruit body, they are divided into two series:

(i) Gynocarpeae: The fruit body is disc shaped i.e., apothecial type. It is also known as Discolichen (e.g., *Parmelia*).

(ii) Pyrenocarpeae: The fruit body is flask-shaped i.e., perithecial type. It is also known as Pyrenolichen (e.g., *Dermatocarport*).

2. Basidiolichen: The fungal member of this lichen belongs to Basidiomycotina *e.g., Dictyonema, Corella.*

Later, Alexopoulos and Mims (1979) classified lichens into three main groups:

i. Basidiolichen: The fungal partner belongs to Basidiomycetes e.g., *Dictyonema*.

ii. Deuterolichen: The fungal partner belongs to Deuteromycetes.

iii. Ascolichen: The fungal partner belongs to Ascomycetes e.g., *Parmelia*, *Cetraria*.

REPRODUCTION IN LICHENS:

Lichen reproduces by all the three means, vegetative, asexual, and sexual.

I. Vegetative Reproduction:

(a) Fragmentation:

It takes place by accidental injury where the thallus may be broken into fragments and each part is capable of growing normally into a thallus. E.g., *Ramalina reticulata*.

(b) By Death of Older Parts:

The older region of the basal part of the thallus dies, causing separation of some lobes or branches and each one grows normally into new thallus.

II. Asexual Reproduction:

1. Soredium (pi. Soredia):

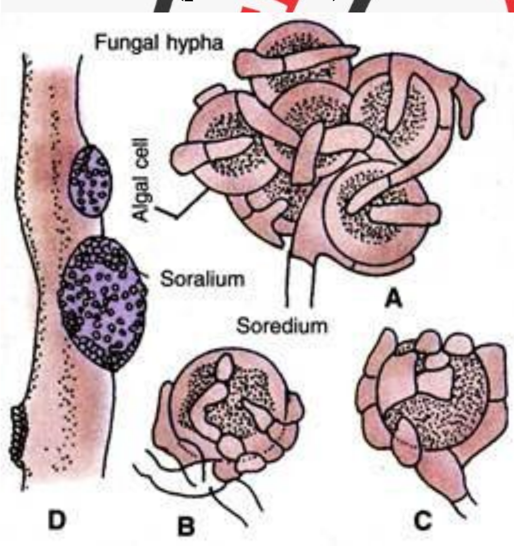


Fig. 20.7 (A–D). *Lichens.* A, single soredium; B–C, stages in the formation of a soredium; D, a thallus bearing soralia.

These are small grayish white, bud-like outgrowths developed on the upper cortex of the thallus (Fig. 20.7A-D). They are composed of one or few algal cells loosely enveloped by fungal hyphae. They are detached from the thallus by rain or wind and on germination they develop new thalli. When soredia develop in an organised manner in a special pustule-like region, they are called Soralia, e.g., *Parmelia*, *Physcia* etc.

2. Isidium (pi. Isidia):

These are small stalked simple or branched, grayish- black, coral-like outgrowths, developed on the upper surface of the thallus (Fig. 18.12C). The isidium has an outer cortical layer continuous with the upper cortex of the mother thallus which encloses the same algal and fungal elements as the mother.

They are of various shapes and may be coral-like in *Peltigera*, rod-like in *Parmelia*, cigar-like in *Usnea*, scale-like in *Collema* etc. It is generally constricted at the base and detached very easily from the parent thallus. Under favourable condition the isidium germinates and gives rise to a new thallus.

In addition to asexual reproduction, the isidia also take part in increasing the photo- synthetic area of the thallus.

4. **Oidia:** Hyphae of few lichens break up into oidia, they germinate into new fungal hyphae and each oidium produces a lichen when comes in contact with suitable alga.

3. Pycniospore:

Some lichen develops pycniospore or spermatium inside the flask-shaped pycnidium (Fig. 20.8A-B). They usually behave as gametes, but in certain condition they germinate and develop fungal

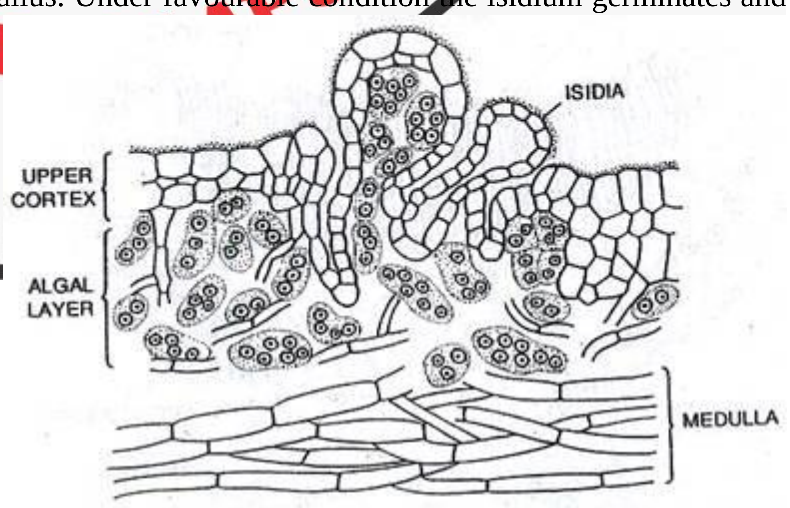


Fig. 18.12. Isidia (*Peltigera* sp.) V.S. thallus.

hyphae. These fungal hyphae, when in contact with the appropriate algal partner, develop into a new lichen thallus.

III. Sexual Reproduction:

Only fungal partner of the lichen reproduces sexually and forms fruit bodies on the thallus. The nature of sexual reproduction in ascolichen is like that of the members of Ascomycotina, whereas in Basidiolichen is like that of Basidiomycotina members.

In Ascolichen, the female sex organ is the carpogonium and the male sex organ is called spermagonium (= pycnidium). The spermogo-nium (Fig. 20.8A) mostly develops close to carpogonium.

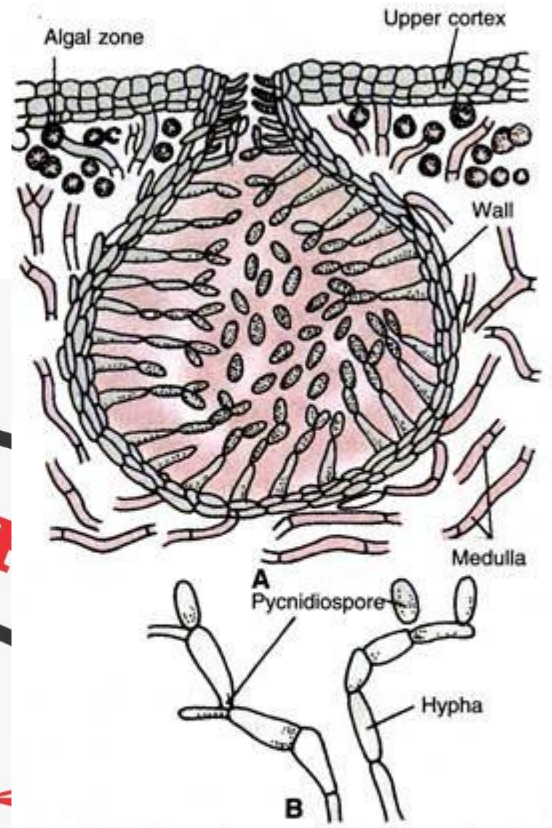


Fig. 20.8 (A-B). *Lichens.* V. S. thallus passing through a pycnidium (A); B, pycnidial hyphae bearing pycnidiospores (highly magnified).

Sex organs:

The female reproductive organ is an ascogonium (carpogonium) which develops from hypha deep in the algal layer. It is a long multicellular hypha, the coiled base of it is the oogonium (Fig 18.15) and the straight portion above it the trichogyne. The ascogonium remains embedded in the algal zone, but the trichogyne projects out beyond the upper cortex. More than one ascogonia may develop at a point where an apothecium is later formed but only one becomes fertile.

The male reproductive body is spermagonium (pycnium). It is flask-shaped cavity immersed in the thallus and opens to the exterior by small ostiole. The fertile hyphae lining the inner surface of the spermagonium produce large number of small non-motile gametes spermatia. The spermatia are functional male gametes.

The spermatia are lodged against the sticky protruding tips of trichogynes, and the fact that ascogonia of thalli lacking spermagonia rarely produce ascocarps. In *Collemodes bachmannianum* a gelatinous lichen trichogyne does not protrude, but grows more or less horizontally in the thallus. Spermatia are borne laterally and terminally on surface of the hyphae with the thallus.

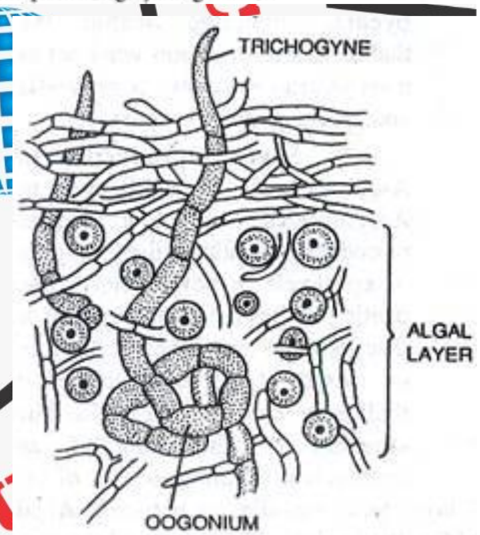


Fig. 18.15. V.S. thallus (*Physcia*).

The growing trichogyne comes in contact with spermatia. The walls of contact dissolve and the male nucleus gradually passes downward to the oogonium, where it fuses with the female nucleus of the egg and the fertilization is effected.

Numerous branched, septate ascogenous hyphae containing one, two or many nuclei developed from the oogonium. The ultimate or the penultimate cells of the ascogenous hyphae develop into asci. At the same time sterile hyphae develop from below the ascogonium and the wall of the ascocarp. As the ascocarp grows it breaks through the thallus and appears, above the surface as a cup or disc or remains embedded.

The development of asci and ascospores resembles to that of typical Ascomycetes. Spores are shed only during moist weather on germination, a spore produces a germ tube which grows in all directions, and as soon as it comes in contact with a suitable alga, additional branches are formed to engulf the alga. Combined growth of the fungus and the alga continues and results in a lichen. In absence of a suitable alga the germ tube dies.

In Ascolichens the fungus belongs to Ascomycetes and the sexual reproduction results in the formation of apothecia or perithecia. These fruiting bodies are small cup-like or disc-like and may be embedded in, or raised above the surface of thallus by short or long stalks. The structure of the wall of an apothecium is similar to that of the thallus; it consists of an upper and a lower cortical layer with medulla, in between. Algal components may not be present in the vegetative part of the apothecium.

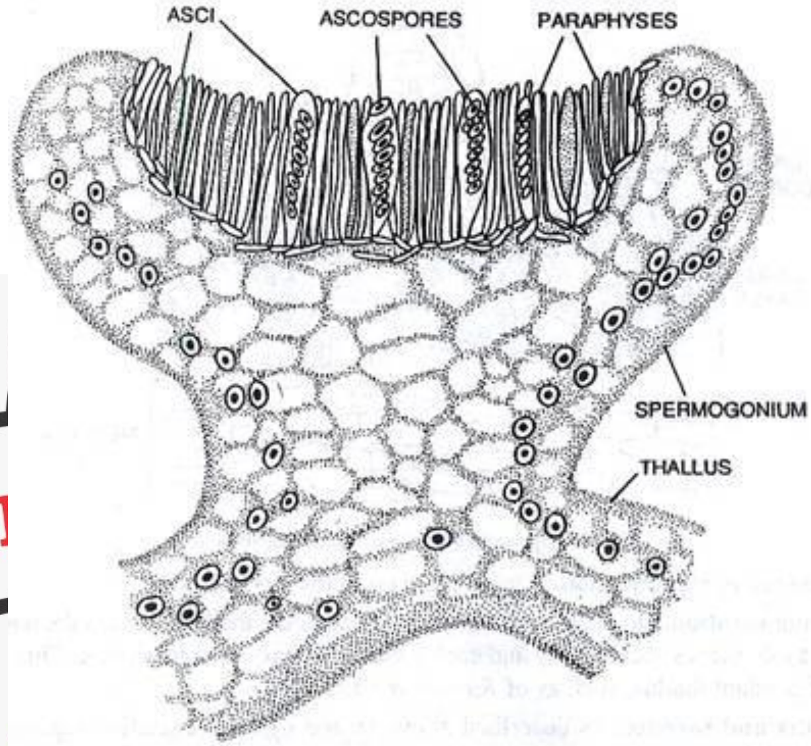


Fig. 18.14. V.S. apothecium (*Physcia*).

The bottom of the cup or the surface of the disc is the fertile part of the apothecium and is lined by the hymenium. Hymenium consists of asci and paraphyses growing vertically. Paraphyses contain a reddish oily substance in them and never project beyond asci. Each ascus contains eight ascospores, which become two celled prior to dissemination. Asci are the resultants of sexual union.

Basidiolichens reproduce by basidiospores produced on basidia as in typical Basidiomycetes. Lower surface of the thallus bears sub hymenium, and basidia are arranged palisade-like on the lowermost face of each subhymenium. Each basidium bears four basidiospores at the tips of sterigmata.

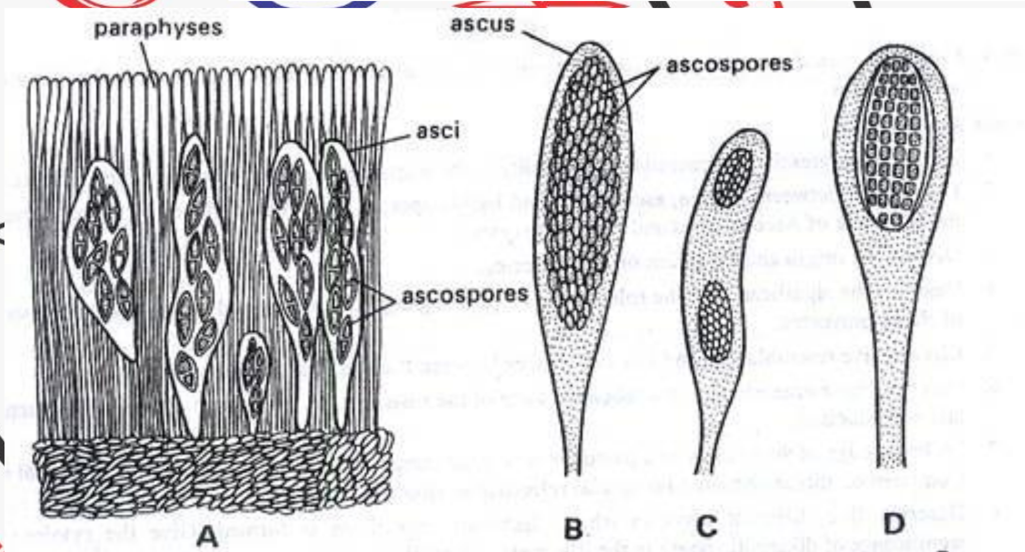


Fig. 18.18. Lichens. A, V.S. of *Physcia* thallus showing asci, ascospores and paraphyses; B, ascus with numerous ascospores; C, bi-spored ascus; D, single spored ascus.

Ecological and Economic importance of Lichens.

A. Ecological Importance of Lichens:

1. Pioneer of Rock Vegetation:

Lichens are pioneer colonisers on dry rocks. Due to their ability to grow with minimum nutrients and water, the crustose lichens colonise with luxuriant growth. The lichens secrete some acids which disintegrate the rocks.

After the death of the lichen, it mixes with the rock particles and forms thin layer of soil. The soil provides the plants like mosses to grow on it as the first successor, but, later, vascular plants begin to grow in the soil.

2. Accumulation of Radioactive Substance:

Lichens are efficient for absorption of different substances. The *Cladonia rangiferina*, the 'reindeer moss', and *Cetraria islandica*, are commonly available lichens in Tundra region. The fallout of radioactive strontium (^{90}Sr) and caesium (^{137}Cs) from the atomic research centres are absorbed by lichen. Thus, lichen can purify the atmosphere from radioactive substances.

3. Sensitivity to Air Pollutants:

Lichens are very much sensitive to air pollutants like SO_2, CO, CO_2 etc.; thereby the number of lichen thalli in the polluted area (cities and industrial areas) is gradually reduced and, ultimately, comes down to nil. The crustose lichens can tolerate much more in polluted area than the other two types. Thus, lichens are used as "pollution indicators".

B. Economic Importance of Lichens:

They are useful to mankind in various ways: as food and fodder, as medicine and industrial uses of various kinds.

1. As Food and Fodder:

Lichens are used as food by human being in many parts of the world and also by different animals like snail, caterpillars, slugs, termites etc. They contain polysaccharide, lichenin; cellulose, vitamin and certain enzymes.

(i) As Food:

Some species of *Parmelia* are used as curry powder in India, *Endocarpon miniatum* is used as vegetable in Japan, *Evernia prunastri* for making bread in Egypt, and *Cetraria islandica* (Iceland moss) as food in Iceland. Other species of *Umbillicaria*, *Parmelia* and *Lecanora* are used as food in different parts of the world. In France, some of the lichens are used in the preparation of chocolates and pastries.

(ii) As Fodder:

Ramalina traxinea, *R. fastigiata*, *Evernia prunastri*, *Lobaria pulmonaria* are used as fodder for animals. Animals of Tundra region, especially reindeer and musk-ox use *Cladonia rangiferina* (reindeer moss) as their common food. Dried lichens are fed to horses and other animals.

Lichens like *Lecanora saxicola* and *Aspicilia calcarea* etc. are used as food by snails, caterpillars, termites, slugs etc.

2. As Medicine:

Lichens are medicinally important due to the presence of lichenin and some bitter or astringent substances. They have been used in the treatment of jaundice, diarrhoea, fevers, epilepsy, hydrophobia and skin diseases.

Cetraria islandica and *Lobaria pulmonaria* are used for tuberculosis and other lung diseases; *Parmelia saxatilis* for epilepsy; *Parmelia perlata* for dyspepsia. *Cladonia pyxidata* for whooping cough; *Xanthoria parietina* for jaundice and several species of *Pertusaria*, *Cladonia* and *Cetraria islandica* for the treatment of intermittent fever.

Usnic acid, a broad spectrum antibiotic obtained from species of *Usnea* and *Cladonia*, are used as antibacterial. *Usnea* and *Evernia furfuracea* have been used as astringents in haemorrhages. Some lichens are used as important ingredients of many antiseptic creams, because of having spasmolytic and tumour-inhibiting properties.

3. Industrial Uses:

(i) Tanning Industry:

Some lichens like *Lobaria pulmonaria* and Cetraria islandica are used in tanning leather.

(ii) Brewery and Distillation:

Lichens like *Lobaria pulmonaria* are used in brewing of beer. In Russia and Sweden, *Usnea florida*, *Cladonia rangiferina* and *Ramalina fraxinea* are used in production of alcohol due to rich content of "lichenin", a carbohydrate.

(iii) Preparation of Dye:

Dyes may be of different colours like brown, red, purple, blue etc. The brown dye obtained from *Parmelia omphalodes* is used for dyeing of wool and silk fabrics. The red and purple dyes are available in *Ochrolechia androgyna* and *O. tartarea*.

The blue dye "Orchil", obtained from *Cetraria islandica* and others, is used for dyeing woolen goods. Orcein, the active principal content of orchil-dye, is used extensively in laboratory during histological studies and for dyeing coir.

Litmus, an acid-base indicator dye, is extracted from *Roccella tinctoria*, *R. montagnei* and also from *Lasallia pustulata*.

(iv) Cosmetics and Perfumery:

The aromatic compounds available in lichen thallus are extracted and used in the preparation of cosmetic articles and perfumes. Essential oils extracted from species of *Ramalina* and *Evernia* are used in the manufacture of cosmetic soap.

Ramalina calicaris is used to whiten hair of wigs. Species of Usnea have the capacity of retaining scent and are commercially utilised in perfumery. *Evernia prunastri* and *Pseudevernia furfuracea* are used widely in perfumes.

Mycorrhiza: General account

Vitadini (1842) was the first to recognise the possible beneficial role of fungal mycelia which mantle the root of higher plants, and this association is named as mycorrhiza (pl. mycorrhizae) i.e., the fungal root, by Frank (1885). Thus mycorrhizae are the symbiotic associations between plant root and fungi, with bidirectional nutrient exchange between the partners.

The autotrophic host plant acts as the carbon source for the fungus, while the fungus supplies mineral nutrients to the plant. About 90% of all land plants are associated with mycorrhiza.

Features of Mycorrhiza:

(i) Absence of any phytopathological symptoms in the partners during the active phase of mutualism,

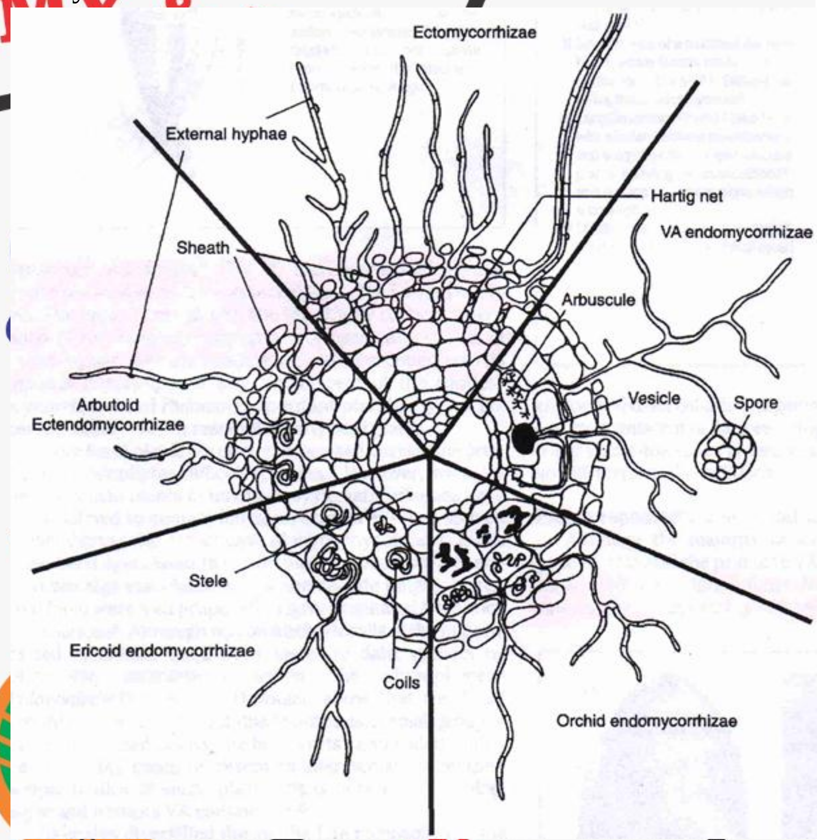
(ii) Presence of complex interfaces between cells of the partners with a predominant type of perisymbiotic membrane, surrounding intracellular symbionts,

(iii) Presence of various types of phagocyte-like structures during establishment of symbionts and during harvesting phase to control the symbiotic population by the host.

Types of Mycorrhiza:

Peterson and Farquhar (1994) classified the mycorrhizae into seven (7) distinct types.

(1) Ectomycorrhizae,
(2) Vesicular-arbuscular mycorrhizae,
(3) Ectendomycorrhizae (Arbutoid),
(4) Ericoid mycorrhizae,
(5) Centianoid mycorrhizae,
(6) Orchidoid mycorrhizae, and
(7) Monotropoid mycorrhizae.



(1) Ectomycorrhizae:

It is commonly called "sheathing mycorrhiza". They occur in 3% of all seed plants. Generally they cause extensive branching and growth of roots and modification of branching pattern, such as racemose type in dicots (*Fagus*) and dichotomous in gymnosperms (*Pinus*). In beech (*Fagus*) the ultimate lateral rootlets are differentiated into 'long' and 'short' roots. The long roots show indefinite growth and their branches are the short roots that are thickened, forked and mycorrhizal. They appear in various colours like white, brown, yellow, black etc., depending on the colour of the fungus. The fungus enters the cortex forming 'Hartig net', but never goes inside the endodermis or stele. They form a mantle of varying thickness.

(2) Vesicular-arbuscular mycorrhizae (VAM):

It is a type of endomycorrhizal association, where both vesicles and arbuscles are developed together. VAM is by far the commonest of all mycorrhizae and has been reported in more than 90% of land plants. They are found in bryophytes, pteridophytes, gymnosperm (except Pinaceae) and most of angiosperms, commonly in Leguminosae (Fabaceae), Rosaceae, Gramineae (Poaceae) and Palmae (Arecaceae).

The VAM is so named because of the presence of two characteristic structures i.e., vesicles and arbuscles:

(i) The vesicles are thin or thick walled vesicular structures produced intra-cellularly and stored materials like polyphosphate and other minerals.
(ii) The arbuscles are repeated dichotomously branched haustoria which grow intracellularly. The arbuscles live for four days and then get lysed releasing the stored food as oil droplets, mostly polyphosphate.

(3) Ericoid mycorrhizae:

This is actually a type of endomycorrhiza. Ericoid mycorrhizae are found in the different members of Ericaceae like *Erica*, *Calluna*, *Vaccinum*, *Rhododendron* etc. The fungi are slow-growing, septate and mostly sterile. During this association the rootlets of the plants are covered by very sparse, loose, dark, septate hyphae that penetrate the cortex forming intercellular coils. After 3-4 weeks the coils degenerate like arbuscles of vesicular-asbuscular mycorrhiza (VAM). Most of the members of Ericaceae grow in acid soil with less amount of P and N nutrition. The fungus gets the photosynthate from the host and improves the mineral uptake and nutrition of the host, especially P and N.

(4) Ectendomycorrhizae (Arbutoid):
Some members of the family Ericaceae and members of other families of Ericales have mycorrhizae intermediate in form between ecto- and endomycorrhizae types, called ectendomycorrhizae. In *Arbustus*, the root system is differentiated into long and short roots. The short roots are swollen and covered by hyphal mantle.

(5) Gentianoid mycorrhizae:
Seedlings of some members of Gentianaceae get infected within 2 weeks of germination. In root, the cortical cells become full of irregular coils of aseptate hyphae. With time the hyphae become lysed. Vesicles are occasionally seen attached to these coils.

(6) Orchidoid mycorrhizae:
Orchids produce millions of tiny seeds per capsule, weighing about 0.3-14µg. The embryo of seeds contains 10-100 cells and there is virtually no storage of food. The embryo is encircled in a thin-walled net-like testa that helps in their dispersal. Thus, majority of seeds are unable to germinate without exogenous supply of carbohydrates. Therefore, mycorrhizal association is obligatory for the seeds to germinate. The fungus provides C-nutrition to the seeds. Initially the fungus enters the embryo and colonises, being restricted to the cortical cells and provides the nutrition. For non-green orchids, this is obligatory throughout their lives.

(7) Monotropoid mycorrhizae:
Monotropa hypopitys is a non-green saprophytic herb. It has short fleshy roots that are invested with a hyphal sheath and often forming Hartig net in the cortical zone. Due to absence of chlorophyll, they are unable to synthesize and supply carbohydrate to the fungus. Boletus is a mycorrhizal fungus associated with roots of both pine and *Monotropa*.

Role of Mycorrhizae in Agriculture and Foresty:

Role in Agriculture:
1. The mycorrhizal association helps in the formation of dichotomous branching and profuse root growth, thus enhances plant growth.
2. Ectotrophic mycorrhiza helps in uptake of mineral ions and also acts as reservoir.
3. They also help in absorption of nutrients.
4. In nutrient deficient soil, the mycelial association helps in the absorption of N, Ca, P, Zn, Fe, Na and others.
5. Mycorrhizal association is obligatory for the germination of orchid seeds.
Mycorrhizal growth in orchids (*Rhizoctonia repens* with *Orchis militaris* tuber tissues) causes the synthesis of phytoalexins — orchinol and hirsinol. Both the compounds act as a barrier to protect infection by other pathogens.
6. Inoculation of VAM as bio fertilizer provides a distinct possibility for the uptake of P in phosphorus-deficient soil.

Role in Foresty:
1. Mycorrhiza plays an important role to establish forest in unfavourable location, barren land, waste lands etc.
2. Trees with facultative endomycorrhiza act as first invader in waste lands as pioneer in plant succession.
3. The application of mycorrhizal fungi in forest bed enhances the formation of mycorrhizal association that prevents the entry of fungal root pathogens.
4. Mycorrhiza mixed nitrogenous compounds such as nitrate; ammonia etc. is available to the plants. Thus it helps in plant growth, especially in acid soil.

PLANT PATHOLOGY

Plant pathology (Gr. pathos — suffering; logos— knowledge) is a branch of botany which deals with the study of the nature, development and control of plant diseases or the study of the suffering plants.

During growth, plants are subjected to environmental conditions which may or may not be favourable. In or with the onset of one or more unfavourable factors of the environment, certain structural and or physiological changes may take place.

On the other hand, in contact with certain organisms, the normal metabolism and/or some structure may alter and ultimately the normal growth of the plant is affected, thus the plants with unusual growth are called diseased plants. Several definitions of diseases of plants have been proposed by different scientists from time to time.

According to the modern concept, disease is an interaction among the host, parasite, and environment.

General account of symptoms

Symptom 1. Anthracnose: These are circular to angular or irregular spots occurring along the stems, petioles, leaf veins and fruits. The affected tissues are finally killed leaving behind characteristic lesions.

Symptom 2. Blight: Blight is a symptom in which the diseased plant is killed suddenly. The pathogen rapidly kills the foliage, blossom and other above-ground parts of the host.

Symptom 3. Callus: This is the outgrowth of tissues in response to wounding.

Symptom 4. Cankers: These are the necrotic lesions, developing in the cortical tissues of stem, leaves or fruits, ultimately resulting in the corky growths in the affected parts.

Symptom 5. Chlorosis: Under this symptom, the normal green pigments of the plant are destroyed and the tissue becomes yellow.

Symptom 6. Curling: Sometimes, the infection of the pathogen results in the abnormal bending of stem, leaves and shoots of the host. This symptom is called 'curling'. It is actually due to the localized overgrowth of cells and tissues.

Symptom 7. Damping-off: In this symptom, the stem of young seedling is affected at the ground level. This results in the toppling down and ultimate death of young seedlings.

Symptom 8. Die-back: Twigs or branches start dying from the tip downward, providing them a burnt appearance in this symptom.

Symptom 9. Discolouration: The colour of the whole plant or several of its parts is changed under this most common symptom of the diseased plants. The usual process or colour change is from green to yellow to brown.

Symptom 10. Dwarfing: This is the subnormal development of most of the plant parts resulting in the reduction of the size of stem, leaves and ultimately the plant height.

Symptom 11. Edema: The eruption or swelling of the epidermal cells of the infected plant is called "edema' or intumescence.

Symptom 12. Elongated Internodes: This is the abnormal elongation of internodes of the infected plant due to hypertrophy (increase in size of the individual cells) and/or hyperplasia (increase in the number of cells due to cell division).

Symptom 13. Etiolation: This is the under-development of chlorophyll in plants developing in insufficient light.

Symptom 14. Exudation (Bleeding and Gummosis): This symptom results in the exuding of fluids from the diseased tissues. If the thick discoloured fluid flows regularly from the diseased tissue, it is called bleeding. But if a gummy substance oozes out from the diseased tissue and dries as a hard gummy mass, it is called gummosis.

Symptom 15. Fasciculation: If several plant organs, such as stem, leaves, flowers and fruits cluster together around a common focus, the symptom is called 'fasciculation'.

Symptom 16. Galls and Tumours: Hypertrophy results in the formation of some irregular-shaped galls ranging from a few mm to 2 or 3 cm. Relatively large, fleshy or hard galls are called 'tumours'.

Symptom 17. Mosaic: Uneven development of chlorophyll resulting in light green patches alternating with dark green areas is the symptom called 'mosaic'. Mosaic is usually the symptom of viral infection.

Symptom 18. Mummification: When fruits become dry due to rotting and form a dark, wrinkled, hard mass, the symptom is called 'mummification'.

Symptom 19. Phyllody: When the infection results in the formation of floral parts (sepals, petals, stamens, etc.) into leaf-like structures, the symptom is called 'phyllody'.

Symptom 20. Prolepsis: When there is a premature development of shoots from buds, the symptom is called 'prolepsis'.

Symptom 21. Rot: When the infection leads to the disintegration of the affected tissues, the symptom is called 'rot'. Based on its nature, it may be soft rot, hard rot, dry rot, black rot, white rot, etc.

Symptom 22. Russetting: When the infection leads to the formation of brownish, superficial roughening of the skin of tubers, fruits, etc., the symptom is called 'russetting'.

Symptom 23. Rust Pustules: These are the small pustules of spores which may be erumpent or submerged, linear or circular, and are often surrounded by chlorotic areas. Rusty pustules may be yellow, light-brown, dark-brown or red in colour. Often formed by members of Uredinales (e.g. *Puccinia*), white rust is caused by *Albugo* while the red rust of tea is caused by an alga *Cephaleuros virescens*.

Symptom 24. Scab: When outgrowth of epidermal and cortical cells results in the formation of ulcer-like lesions on tubers, stem, leaves and fruits, the symptom is called 'scab'.

Symptom 25. Smuts: These are the malformations, containing masses of spores which provide the colony a colour of deep brown or dark black to the affected parts, such as stem, leaves, inflorescence and rarely to the underground parts of the host plant.

Symptom 26. Spots: Spots are the necrotic symptoms of different shapes, sizes and colours. They may be isolated or may coalesce in the later stages.

Symptom 27. Streaks and Stripes: The streaks are the linear lesions which develop due to infection on the leaf blade, leaf sheath and stem. The enlarged streaks form stripes.

Symptom 28. Variegation: This is a pattern of white patches formed by the non-development of chlorophyll in certain cells of the host due to the infection of the pathogen.

Symptom 29. Vein-clearing: This is viral symptom developed due to the inhibition of chlorophyll formation in the veins of the host.

Symptom 30. Wilting: The drooping condition of plant resulting from the vascular infections of the roots and stem is called "wilting'.

Symptom 31. Witches Broom: When the infected branches of the host become abnormally erect, the symptom is called 'witches broom'.

CLASSIFICATION OF PLANT DISEASES

Based on plant part affected
Localized, if they affect only specific organs or parts of the plants.
Systemic, if entire plant is affected. or
They can be classified as root diseases, stem diseases, foliage/foliar diseases, etc.

Based on perpetuation and spread
Soil borne -when the pathogen perpetuates through the agency of soil.

Seed borne -when the pathogen perpetuates through seed (or any propagation material).

Air borne -when they are disseminated by wind e.g. rusts and powdery mildews.

Based on the signs and symptoms produced by the pathogens
Diseases are classified as rusts, smuts, powdery mildews, downy mildews, root rots, wilts, blights, cankers, fruit rots, leaf spots, etc. In all these examples, the disease are named after the most conspicuous symptom of the disease appearing on the host surface.

Based on the host plants affected
They can be classified as cereal crop diseases, forage crop diseases, flax diseases, millet diseases, plantation crop diseases, fruit crop diseases, vegetable crop diseases, flowering plant diseases, etc.

Based on major Causes
They can be classified as fungal diseases, bacterial diseases, viral diseases, mycoplasmal diseases, etc.

Based on Infection Process
Infectious -All the diseases caused by animate causes, viruses and viroids can be transmitted from infected host plants to the healthy plants and are called infectious.

Non-infectious- Non-infectious diseases cannot be transmitted to a healthy plant. Also referred as non-parasitic disorders or simply physiological disorders, and are incited by abiotic or inanimate causes like nutrient deficiency or excess or unfavorable weather conditions of soil and air or injurious mechanical influences.

Classification of Animate Diseases in Relation to Their Occurrence
Endemic diseases -which are more or less constantly present from year to year in a moderate to severe form in a particular geographical region, i.e. country, district or location.

Epidemic or epiphytotic diseases - which occur widely but periodically particularly in a severe form. They might be occurring in the locality every year but assume severe form only on occasions due to the favourable environmental conditions occurring in some years.

Sporadic diseases occur at irregular intervals and locations and in relatively few instances.

Pandemic diseases: A disease may be endemic in one region and epidemic in another. When epiphytotics become prevalent throughout a country, continent or the world, the disease may be termed as pandemic.

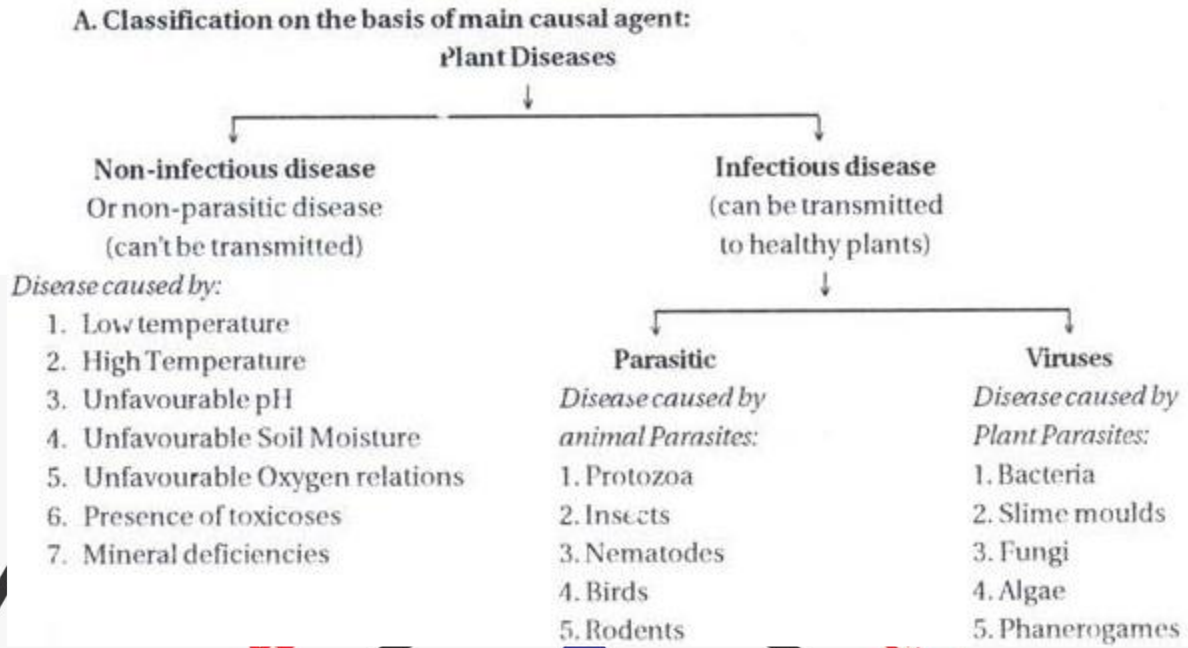
Disease triangle
The interaction of the host, the pathogen and the environment results in disease development. It is generally illustrated by a triangle, also called a disease triangle.

Disease Development in Plant Population This is determined by:
Host: All conditions in host that favour susceptibility.

Pathogen: Total of virulence, abundance etc.

Environment: Total of conditions that favour the pathogen and predispose the host plants to pathogen attack.

Time: Specific point of time at which a particular event in disease development occurs and the duration or length of time during which the event takes place.



Pathogen etiology, Disease development and transmission, Pathogenesis and saprogenesis

Pathogenesis is the stage of disease in which the pathogen is in intimate association with living host tissue. Three fairly distinct stages are involved:

Inoculation: transfer of the pathogen to the infection court, or area in which invasion of the plant occurs (the infection court may be the unbroken plant surface, a variety of wounds, or natural openings—e.g., stomata [microscopic pores in leaf surfaces], hydathodes [stomata-like openings that secrete water], or lenticels [small openings in tree bark])

Incubation: the period of time between the arrival of the pathogen in the infection court and the appearance of symptoms

Infection: the appearance of disease symptoms accompanied by the establishment and spread of the pathogen.

One of the important characteristics of pathogenic organisms, in terms of their ability to infect, is virulence. Many different properties of a pathogen contribute to its ability to spread through and to destroy the tissue. Among these virulence factors are toxins that kill cells, enzymes that destroy cell walls, extracellular polysaccharides that block the passage of fluid through the plant system, and substances that interfere with normal cell growth. Not all pathogenic species are equal in virulence—that is, they do not produce the same amounts of the substances that contribute to the invasion and destruction of plant tissue. Also, not all virulence factors are operative in a particular disease. For example, toxins that kill cells are important in necrotic diseases, and enzymes that destroy cell walls play a significant role in soft rot diseases.

Many pathogens, especially among the bacteria and fungi, spend part of their life cycle as pathogens and the remainder as saprotrophs.

Saprogenesis is the part of the pathogen's life cycle when it is not in vital association with living host tissue and either continues to grow in dead host tissue or becomes dormant. During this stage, some fungi produce their sexual fruiting bodies; the apple scab (*Venturia inaequalis*), for example, produces perithecia, flask-shaped spore-producing structures, in fallen apple leaves. Other fungi produce compact resting bodies, such as the sclerotia formed by certain root- and stem-rotting fungi (*Rhizoctonia solani* and *Sclerotinia sclerotiorum*) or the ergot fungus (*Claviceps purpurea*). These resting bodies, which are resistant to extremes in temperature and moisture, enable the pathogen to survive for months or years in soil and plant debris in the absence of a living host.

ANIMATE PATHOGENS
FUNGAL DISEASES:

NAME OF THE DISEASE	CAUSAL ORGANISM
Koleroga of Arecanut -	*Phytophthera palmivora*
Late blight of potato**-**	*Phytophthera infestans*
Loose smut disease of *Sorghum* -	*Sphacelotheca sorghii*
Red rot of sugarcane **-**	*Colletrorichum falcatum*
Coffee rust **-**	*Hemileia vastatrix*
Blast disease of rice **-**	*Pyricularia oryzae*
Wheat Rust **(**Black or stem rust)-	*P. graminis tritici*
Orange or brown rust of Wheat-	*P. recondita*
Yellow or stripe rust of wheat-	*P. striiformis*
Early blight of potato-	*Alternaria solani*

BACTERIAL DISEASE:

NAME OF THE DISEASE	CAUSAL ORGANISM
Citrus canker -	*Xanthomonas citrii*
Blight of Paddy-	*Xanthomonas oryzae*
Brown rot of potato-	*Pseudomonas solanacearum*
Ring rot of potatoes-	*Corynebacterium sepedonicum*
Yellow ear rot or Tundu disease of wheat	*C. tritici*

VIRAL DISEASE:

NAME OF THE DISEASE	CAUSAL ORGANISM
Tomato leaf curl -	*Begomovirus* or Tomato yellow leaf curl virus
Papaya leaf curl -	Papaya leaf curl virus or Tobacco leaf curl virus (*Tobacco virus 16* or *Nicotiana virus 10*)
Yellow mosaic of beans -	Bean yellow mosaic virus
Tobacco and Tomato mosaic-	*Nicotiana virus 1*
Mosaic disease of potato-	Virus X or Virus A
Leaf roll of Potato-	Leaf roll virus, YX and A *Solanum virus* 14

MYCOPLASMA DISEASE:

NAME OF THE DISEASE

Yellows disease
Little leaf of Brinjal
Citrus greening
Sandal spike disease
Grassyshoot of sugarcane
Rice yellow dwarf
Cotton little leaf

ALGAE: *Cephaleuros virescens* is a parasite of *Magnolia, Rhododendron, Camellia sinensis* and *Piper nigrum.*

PHANEROGMIC PARASITES:

Dodder (*Cuscuta reflexa, C. hyaline* and *C. chinensis)* is a stem parasite belongs to family convolvulaceae infects any plant. Broomrape (*Orobanche cenua)* is a root parasite of Orobanchaceae infects solanaceous and cruciferous. *Viscum, Dendrophthoe* and *Santalum* are partial stem parasites. Scrophulariaceae members are partial root parasites. Ex: *Striga lutea* Parasite on roots of *Sorghum.*

NEMATODES: belong to order Tylenchiad, Class- Nematoda, Phylum- Nemathelminthes.

INANIMATE PATHOGENS-

Includes adverse environment without parasites. Low or high temperature, light effects, soil moisture disturbance, oxygen relations, effect of atmospheric impurities, lightning injury and nutritional disorders also cause symptoms.

MODE OF INFECTION:

Mechanism 1. Dissemination by Seed:

Pathogens may be carried inside or outside the seeds or fruits functioning as seeds. The infective materials may be mycelium, spores or any other part of the pathogens.

Mechanism 2. Dissemination by Propagating Stock:

This is rather common in cases where plants are multiplied by using propagating stocks and is partly common with the virus diseases, as in Mosaic disease of Sugarcane. Here the propagating stocks behave as carriers of the pathogens.

Mechanism 3. Dissemination with Plant Debris:

During cleaning of soil prior to sowing of seeds, previous year's infected plant debris should be thoroughly removed and burnt. But very often the infected plant debris instead of being burnt off is carelessly transported from place to place resulting in the dissemination of pathogens and spread of the diseases.

Mechanism 4. Dissemination with Manure:

Pathogens are disseminated when manures like, compost and cow dung are used particularly in seed bed soil contaminated with various pathogens.

Mechanism 5. Dissemination with Soil:

Transference of soil from one area to the other is a very common practice. When such soil is contaminated with pathogen knowingly or unknowingly contamination 'through soil is spread.

Mechanism 6. Dissemination by Field Operations and Implements:

Pathogens may be disseminated by field operations, such as, transplanting of seedling, watering, weeding, harvesting operations and through implements.

Mechanism 7. Dissemination by Insects:

Insects play a very important role in the dissemination of plant diseases. The mechanism of dissemination, however, is extremely variable which depends on the nature of insects and the nature of inoculum of the diseases. Again the insects may play direct or indirect role.

As to direct role, the inoculum may be carried:

(i) On the body of the insects,

(ii) In the body passing through the alimentary tract when they feed on the inoculum along with other exudates, or

(iii) As they feed on diseased host tissue they carry the inoculum and spread infection.

Mechanism 8. Dissemination by Animals Other Than Insects:

Nematodes, snails, birds, and wild and domestic animals often help dissemination of plant diseases.

Mechanism 9. Dissemination by Air Currents:

The spores of many parasitic fungi are disseminated by air currents from diseased to disease-free host. Besides this, the air currents may indirectly help dissemination of plant diseases. For example, diseased plant parts may be caught up by air currents and brought to distant places to spread disease.

Mechanism 10. Dissemination by Water:

The dissemination of pathogens by water may be in two ways:

(i) Flagellate spores of pathogenic fungi are entirely dependent on the supply of water for their dissemination, example, and Wart disease of potato;

(ii) Pathogens like, bacteria are often disseminated by splashing of raindrops, as in case of Citrus canker disease

(iii) Dissemination of conidia of red rot fungus (*Colletotrichum falcatum*) takes place through flowing irrigation water or rain water

Mechanism 11. Dissemination by Exporting and Importing of Commodities:
That diseases are disseminated during exporting and importing various commodities is very well-known.
This may happen in different ways:
(i) With contaminated commodities
(ii) With contaminated containers of the commodities
(iii) With both contaminated commodities and containers.

Mechanism 12. Dissemination by Natural Root Grafting:
Where natural grafting between the roots of diseased and disease-free plants takes place resulting in the spread of the disease.

Mechanism 13. Dissemination by Shooting Out of Spores:
In *Taphrina deformans*, the causal organism of Peach leaf curl disease, the ascospores are shot out from the asci, come in contact with the host, and cause infection and thereby the disease is disseminated.

Mechanism 14. Dissemination through Angiospermic Plant:
Pea mottle virus is transmitted by *Cuscuta campestris*.

Mechanism 15. Dissemination through Pollen Grains:
Tobacco ring spot virus and Potato spindle tuber virus are transmitted through pollen grains.

Mechanism 16. Dissemination through Other Media:
Sclerotia of *Claviceps purpurea* unknowingly remain mixed with healthy rye seeds to help dissemination of disease being the source of inoculum. Besides this, mummified apples and pears also serve as source of inoculum for seasonal carry over and incidence of disease in orchards.

Management of fungal diseases (Plant Disease Management)

The word 'control' is a complete term where permanent 'control' of a disease is rarely achieved whereas, 'management' of a disease is a continuous process and is more practical in influencing adverse affect caused by a disease. Disease management requires a detail understanding of all aspects of crop production, economics, environmental, cultural, genetics and epidemiological information upon which the management decisions are made.

A. Principles of plant disease management: There is six basic concept or principles or objectives lying under plant disease management.

1. **Avoidance of the pathogen**: Occurrence of a disease can be avoided by planting/sowing a crop at times when, or in areas where, inoculum remain ineffective/inactive due to environmental conditions, or is rare or absent.

2. **Exclusion of the pathogen**: This can be achieved by preventing the inoculum from entering or establishing in a field or area when it does not exist. Legislative measures like quarantine regulations are needed to be strictly applied to prevent spread of a disease.

3. **Eradication of the pathogen**: It includes reducing, inactivating, eliminating or destroying inoculum at the source, either form a region or from an individual plant (rogueing) in which it is already established.

4. **Protection of the host**: Host plants can be protected by creating a toxin barrier on the host surface by the application of chemicals.

5. **Disease resistance**: Preventing infection or reducing the effect of infection of the pathogen through the use of resistance host which is developed by genetic manipulation or by chemotherapy.

6. **Therapy**: Reducing severity of a disease in an infected individual.

The first five principles are prophylactic (preventive) procedure and the last one is curative.

B. Methods of plant disease management

1**. Avoidance of the pathogen:**
 i. Choice of geographical area
 ii. Selection of a field

iii. Adjustment of time of sowing
iv. Use of disease escaping varieties
v. Use of pathogen-free seed and planting material
vi. Modification of cultural practices

2. **Eradication of the pathogen**
i. Biological control of plant pathogens
ii. Eradication of alternate and collateral hosts
iii. Cultural methods:
a. Crop rotation
b. Sanitation of field by destroying/burning crop debris
c. Removal and destruction of diseased plants or plant parts
d. Rouging
iv. Heat and chemical treatment of diseased plants
v. Soil treatment: by use of chemicals, heat energy, flooding and fallowing

3. **Protection of the host**
i. Chemical control: application of chemicals (fungicides, antibiotics) by seed treatment, dusting and spraying
ii. Chemical control of insect vectors
iii. Modifications of environment
iv. Modification of host nutrition

4. **Disease resistance**
Use of resistant varieties: Development of resistance in host is done by
i. Selection and hybridization for disease resistance
ii. Chemotherapy
iii. Host nutrition
iv. Genetic engineering, tissue culture

5. **Exclusion of inoculum of the pathogen**
i. Treatment of seed and plating materials
ii. Inspection and certification
iii. Quarantine regulations
iv. Eradication of insect vector

6. **Therapy**
Therapy of diseased plants can be done by
i. Chemotherapy
ii. Heat therapy
iii. Tree-surgery

1. Cultural Methods:

(a) Selection of Geographical area: which on the basis of the favourable temperature and humidity requirement for a particular crop but unflavored to the fungi and bacteria.

(b) Selection of field: Many soil borne diseases are controlled by proper selection of the field. It is quite possible that a particular field soil contains a pathogen species. In that case the particular crop is not sown in that field for several years. Water drainage is also taken care of while selecting the field.

(c) Choice of the time of sowing: The susceptible stage of plant growth and the favourable environment for pathogen should not match at the same time.

(d) Disease escaping varieties: Certain varieties of crop due to their growth characteristics are able to escape from disease. This disease escaping characteristics of the crop is not genetic rather it is due to growth habits and time of maturation.

(e) Selection of seed: To avoid seed borne diseases, healthy and disease free seeds are essential.

(h) Modification of cultural Practices: Cultural practices such as – distance between the plants, time and frequency of irrigation, transplantation time and method, mixed cropping, amount and property of fertilizer and compost etc. can be changed to reduce losses caused by the disease.

(i) Eradication of Insect Vectors: Insects serve as vectors for many diseases. Eradication of such insect vectors is essential for the control of pathogens.

Eradication of the pathogen

(i) Biological Control:

In this method the pathogen actively is reduced through the use of other living organisms e.g., hyper-parasites, resulting in a reduction of disease incidence and severity.

(ii) Elimination of Alternate, wild and Weed Hosts:

Many weeds particularly biennial and perennial ones are potential sources of infection. They harbour the pathogens which later infect the cultivated crops seeded in the same soil. Elimination of these wild and alternate hosts is a very effective measure of disease control.

(iii) Crop rotation: Crop rotation is essential for controlling soil borne diseases and pathogens.

(iv) Rogueing: Removal and Destruction of Diseased Plant Organs, eradication of alternate and collateral hosts and sanitation of Fields.

(v) Prevention of the Disease Carried by the Plant Parts:

Normally the seeds, tubers, rhizomes, bulbs, etc., carry heavy loads of disease causing organisms or their spores. Under favourable conditions they cause disease. In such cases the disinfection of these infected plant organs by using sterilising agents, before they are sown, is quite effective.

2. Physical Methods:

(a) The hot water treatment method of Jensen was developed in 1887 which was used to control loose smut disease of wheat, barley and Oats. Until the development of systemic fungicide hot water treatment was the only method to control loose smut. Hot water treatment is also effective in the control of nematodes.

(b) Solar energy treatment to control loose smut was first developed by Lutlzra. In this method seeds are first rinsed or soaked in water for 4-5 hrs before drying them in scorching sun.

(c) Hot air treatment for the control of virus in propagating stocks was first developed by Kunkal in Peach yellow.

3. Chemical Methods:

(a) Seed treatment with fungicide before transplanting.

i. Soil treating chemicals:

It is used for controlling such soil borne diseases which attack on seeds or seedlings. The examples of such chemicals are – Formaldehyde, Captan, Thiram, Zineb, Organo-mercurials, PCNB, Ethylene dibromide, vapam etc.

ii. For Externally seed borne diseases, chemicals such as formalin, copper carbonate, captan, organo-mercurials (Agrosan GN and Ceresan) are used for seed treatment.

iii. For Internally seed borne diseases (i.e. loose smut), hot water treatment and solar treatment are used.

iv. Systemic Organic Compounds are effective chemicals for controlling both externally and internally seed borne diseases eg. Oxanthin derivatives (Plantvax and Vitavax), Benlate, Bavistin, Demosan.

v. For controlling air borne diseases, foliar application of chemicals is more effective.

vi. The common copper fungicides are: Perenox, Perelan, Blitox, Cuprokyt, Cuprosan and Fytolan. Its use is comparatively better than that of Bordeaux mixture.

(b) Seed dressing with organomercurials and systemic fungicides.

ii. Antibiotics:

The use of antibiotics is the most recent development in plant chemotherapy. It is receiving increasing attention. The antibiotics are most effective in the control of bacterial plant pathogens. However, their use as disease controlling agents in general is still in the experimental stage. Ex: Sterptomycin, Tetracyclin, Cycloheximide, Griseofulvin, etc.,

iii. Growth regulators: Kinetin, Maleic hydrazide, Gibberelic acid also helps in disease control.

iv. Host Resistance:

Resistance is the character of a plant which suppress pathogen and disease development. The use of resistant genotypes is a highly effective approach to suppress disease to tolerable levels. Resistance alone is sometimes sufficient to suppress disease to tolerable levels. In resistant genotypes, disease appears late, build up slowly and results in little damage to the crop.

4. Plant Quarantine:

Plant quarantine can be defined as a legal restriction on the movement of agricultural commodities for the purpose of exclusion, prevention or delay the establishment of plant pests and diseases in areas where they are not known to occur.

1. Koleroga or Mahali or fruit rot of Arecanut

Division: Mycota
Class: Phycomycetes
Order: Peronosporales
Family: Pythiaceae
Genus: *Phytophthora*
Species: palmivora

INTRODUCTION:

Arecanut is an important commercial crop cultivated in tropical, rainfall areas and in India (Western peninsular- Mumbai, Malabar, Cochin, Assam). Among the many reported diseases, fruit rot (commonly called as *"Koleroga"* in kannada or *"Mahali"* in malayalam) is a serious disease that could lead to great economic losses. The disease may cause fruit drop of 50 to 100 per cent in individual palms if timely and proper control measures are not adopted. Fruit rot disease occurs in all the arecanut growing regions receiving heavy rainfall during southwest monsoon period (June to September).

HOST: Arecanut *(Areca catechu).*

THE PATHOGEN OR CAUSAL ORGANISM:

Fruit rot of arecanut is caused by the fungus *Phytophthora palmivora (arecae)*, *P. meadii* and *P. heveae* were also reported to be involved in the disease. Bud rot and crown rot diseases caused by the same fungus occur either as a further manifestation of the fruit rot infection or independently as fresh infection during the monsoon and subsequent cooler months. Mycelium is coenocytic, sporangiophores are wide, irregularly sympodial, sporangia are broadly ellipsoid/ obturbinate to spherical. The fungus reproduce as oospores, chlamydospores (Variable in number, sometimes absent or rare but never abundant) and development of sporangia need strong light and divides within 4 hours into zoospores which are released with more light and humidity. No sexual reproduction naturally but in medium oogamous type.

SYMPTOMS:

• Starts after 2 – 3 weeks of rainy season.
• Initial symptoms appear as dark green/ yellowish water-soaked lesions on the nut surface near the perianth (calyx) from base, which is the chlorosis stage (Neergole), as advances fungus develops on outside of the fruit (Bhusargole).
• Characteristic symptom is rotting and extensive shedding of the immature nuts which lie scattered near the base of the tree.
• The infected nuts lose their natural green lusture, quality and hence have a low market value.
• The lesions on the fruits gradually spread covering the whole surface before or after shedding which consequently rot.
• White mycelial mass envelopes on entire surface of the fallen nuts.
• As the disease advances the fruit stalks and the axis of the inflorescence rot and dry, sometimes being covered with white mycelial mats.
• Infected nuts are lighter in weight and possess large vacuoles
• Infection occurring later in the season results in rotting and drying up of nuts without shedding called *'Dry Mahali'*
• The infection of heart leaf results in bud rot and crown rot initiates from the outermost leaf sheath, gradually spreads towards the growing bud and results in withering of leaves and bunches.

SPREAD OF DISEASE OR DISEASE CYCLE AND PREDISPOSING FACTORS:

The fungus is endophytic and survives as oospores, chlamydospores and mycelium in soil, on fallen nuts, on dried nuts and on inflorescence remaining in the crown.

The severity, persistence and spread of fruit rot are related to the pattern of rain. The disease appears usually 15 to 20 days after the onset of regular monsoon rains and may continue up to the end of the rainy season.

Continuous heavy rainfall coupled with low temperature (20 to 23 °C), high relative humidity (>90%) and intermittent rain and sunshine hours favour the occurrence of fruit rot.

Disease spread is through heavy wind and rain splashes. The fruit bunches infected towards the end of rainy season may remain mummified on the palm and such nuts provide inoculums for bud rot or crown rot or the recurrence of fruit rot in the next season.

DISEASE MANAGEMENT OR CONTROL MEASURES:

Before the onset of monsoon

• Follow phytosanitary measures such as removal of all dried and infected bunch of last season attached to the palm.
• Spray one per cent Bordeaux mixture on the bunches before the onset of monsoon as a prophylactic measure.
• Cover the areca bunches with polythene covers before the start of the heavy monsoon showers.
• Spray one per cent Bordeaux mixture: The initial spray is to be done immediately after the onset of monsoon showers and the second spray after an interval of 40 to 45 days. If monsoon prolongs, third spray should be given.
• A fine spray will be needed for effective spread of spray fluid over the surface of the nuts. Spraying operations are to be undertaken on clear sunny days.
• Collect and destroy of all fallen and infected nuts to prevent the spread of disease.
• Severe incidence of fruit rot during monsoon may lead to the incidence of bud rot and crown rot diseases. Hence, preventive measures to be taken up to control these diseases as well.
• Remove the infected tissues from the crown and treat the wound/ cut end with 10% Bordeaux paste. Cover the treated bud with protective covering till the normal shoot emerges.
• Copper fungicides such as Perenox, Blitox 50, Fytolan is used to control the disease.

2. DISEASE: Coffee rust

Division: Mycota
Class: Basidiomycetes
Order: Uredinales
Family: Pucciniaceae
Genus: *Hemileia*
Species: vastatrix

INTRODUCTION:

Coffee originates from high altitude regions of Ethiopia, Sudan and Kenya and the rust pathogen is believed to have originated from the same mountains. Arabs brought it to Yemen and unknowingly introduced in the hills of South India.
Classical plant disease of international importance. It appeared in Sri Lanka in 1868 and by 1875 spreaded more and lead to abandoned coffee plantations. Also spread to south India and central Africa in 1913.

HOSTS: *Coffea arabica* (arabica coffee) is most susceptible, *Coffea liberica* is least susceptible and ***Coffea canephora*** (robusta coffee) is intermediate.

THE PATHOGEN OR CAUSAL ORGANISM: *Hemileia vastatrix* - currently found in nearly all the world's coffee-growing regions. *H. coffeicola* - restricted to central and western Africa, especially the higher and cooler regions. The mycelium is intercellular, branched, septate, interwoven feeder hyphae with haustoria and rounded cells below the stomata, bearing clavate filaments with small pedicels containing spores which emerge through the stomata. New uredospores arise from the same stalk lower down, each stalk produce several uredospores and becoming sometimes like a swollen basal cell.

Uredospores will not shed immediately, but remain attached to pedicels by short sterigmata. In mature uredium the pedicels lose their individuality and form a compound column at the ends and sides of which a densely crowded mass of sterigmata carries the spores. Uredospores are reniform, wall hyaline, strongly warted on convex surface, smooth on the straight or concave face.

Teliospore arise in same sorus with spherical or turnip shaped, hyaline wall smooth. These germinate without a rest period and in situ.

SYMPTOMS:

Yellowish-orange, powdery, rounded blotches occur on the underside of leaves, which may coalesce with others to form an irregularly shaped lesion which correspond to a chlorosis of the upper surface. Later, the centre of the old pustules becomes necrotic. Premature defoliation and die-back of the branches can occur. The disease is restricted to the leaves, but on rare occasion seen on berries and young shoots.

DISEASE CYCLE:
Shelter from wind, intermittent rain, dew or moist, ample light, very light overhead shade and moderately high temperature predispose the plants to severe attacks. Rain splash spread to short distance, Two species of thrips have been found feeding on and dispersal of uredospores in India.

DISEASE CONTROL:
Although the use of fungicides is one of the preferred immediate control measures, the use of resistant cultivars is considered to be the most effective and durable disease control strategy.
Spraying of Copper fungicides at proper time.
Maintain proper field sanitation.

3. Grain smut/Kernel smut / Covered smut / Short smut –
Division: Mycota
Class: Basidiomycetes
Order: Ustilaginales
Family: Ustilaginaceae
Genus: *Sphacelotheca*
Species: sorghi

INTRODUCTION: It is present in Africa, Asia, Europe and North, Central And South America. In India, it is distributed in Andhra Pradesh, Maharashtra, Karnataka, Madhya Pradesh and Tamil Nadu.

HOSTS: *Sorghum*

THE PATHOGEN OR CAUSAL ORGANISM: *Sphacelotheca sorghi*
The mycelium is mostly intercellular without haustoria, sparsely branched, septate and hyaline. The primary mycelium formed by the germination of basidiospores enters the host through seedlings.
When the primary mycelium of the opposite strain also happens to enter the same seedling, dikaryotic mycelium is formed through anastomosis and fusion. This dikaryotic mycelium grows with the seedling and produces the smut sori in the ovaries.
The Spore mass is dark brown, surrounding a central columellar of the host tissue. The Spores are Globose to sub globose, olivacious brown, finely echinulate and germinate immediately with viability for considerable period of time.

SYMPTOMS:
The fungus attacks the ovaries and all the ovaries in the head are turned into sori of the smut. The normal grain is thus replaced by an oval or cylindrical dirty grey sac with a slightly conical tip. Subtending the sac and the glumes of the spikelets, the sorus is covered by a tough membrane and remains intact without rupturing early.
In most cases stamens are absent but the stigma is not transformed. However other floral parts of the host are not affected.

DISEASE CYCLE AND PREDISPOSING FACTOR:
It is an externally seed borne disease. During threshing, the teleutospores are released from the infected ovaries and get lodged on the surface of seeds. These remain viable for a maximum of period of five years. Generally in the next season, in presence of water the teleutospores germinate to produce a three celled promycelium which through budding produces terminal as well as lateral sporidia. The promycelium may also act as infection hyphae which may enter the seedlings of the host. Environment influence the intensity of infection. Temperature of 25ºC and medium to low soil moisture is favourable for infection.

DISEASE MANAGEMENT OR CONTROL MEASURES FOR ALL SMUTS
Seed disinfection: Treat the seed with Captan or Thiram at 4 g/kg.

Steeping the grains in 2% $CuSO_4$ for 15min or in 0.5% formaldehyde for 1-2 hrs.

Copper carbonate, Sulphur fine powder can be used.

Use disease free seeds.

Follow crop rotation.

Collect the smutted ear heads in cloth bags and bury in soil.

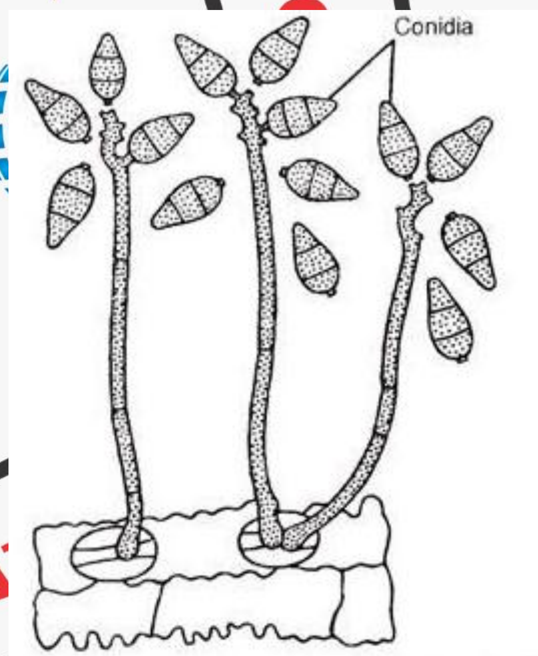
Resistant varieties like Milo, Hegari, Feterita and Shatung can be grown.

4. Blast Disease of Rice:
Division: Mycota
Class: Phycomycetes
Order: Peronosporales
Family: Albuginaceae
Genus: *Pyricularia*
Species: *oryzae*

INTRODUCTION: Blast disease has been reported from almost 70 rice growing countries of the world and is a major problem causing loss upto 90% depending upon the part infected. This disease is most destructive in South Indian coastal areas, Andhra Pradesh, Tamil Nadu, Kerala, Maharashtra, Gujarat, Orissa and Jammu and Kashmir.

HOSTS: *Oryza sativa* L. (Family – Gramineae i.e., Poaceae).

THE PATHOGEN OR CAUSAL ORGANISM: -*Pyricularia oryzae***:**
This is the enemy number one of rice crop and occurs in India frequently. Mycelium is Septate, multinucleate, branched hyphae. Conidiophores single or in fascicles, simple, rarely branched showing sympodial growth. Conidia formed singly at the tip of the conidiophore at points arising sympodially and in succession, pyriform to obclavate, narrowed towards tip, rounded at the base, 2-septate, rarely 1 or 3 septate, hyaline to pale olive, with a distinctly protruding basal hilum. Conidia are smooth, thick walled, Globose, ovoid or oblong and germinate on host plant through appressoria at the tips of germ tube.
Chlamydospores are formed in culture. The perfect stage of fungus is not yet known.
The pathogen produces 2 toxic substances- piricularin and α-picolinic acid which inhibit with growth of rice seedlings.



5.10 : Blast disease of rice (c.o. *Pyricularia grisea*) : Conidiophores with attached and detached conidia

SYMPTOMS:
Spindle-shaped spots or lesions, ash-coloured in centre with brown margins, appear on the leaves, leaf sheaths, culms, glumes, the stalk (neck) of the panicle and foliage may be completely blasted. Lesions on the neck of the culm and panicle branch bases result in typical rotten necks with nodal infections too. The ears are also infected and bend downward due to rotting of the stalk.
Leaf spots are usually small, water soaked, elliptical with pointed ends. Colour varies from grey or white with brown or red or yellow margin. However shape and colour vary depending on environment, the age of spot and susceptibility of rice. Brown to black spots or rings are seen on rachis of maturing inflorescence or on ears. The most characteristic symptom appear on culm. The neck becomes shriveled and covered with a grey fluffy mycelium. The affected plants can be easily identified by examining the bluish patches on neck or the stem. If it

is infected before grain formation, no grains are formed and panicle hangs down. However, due to necrosis of neck tissues, the ear tends to break and fall off.

THE DISEASE CYCLE (= LIFE CYCLE OF THE PATHOGEN):

The conidia survive in plant debris, in soil, or on the collateral hosts. When the rice crop is available, the wind-blown conidia land on the leaves. On germination, the germ tubes enter the leaves to establish an intra-cellular mycelium. The fungus grows inside the host tissues and forms conidiophores which emerge through the stomata and bear conidia. The conidia spread the infection throughout the season. When the crop is harvested, they remain in the debris, left behind in the fields. Alternatively, the conidia may infect and live on other collateral hosts, until the next rice crop is available.

The fungus survives hot dry month in tropic and cold winter in subtropic and temperate rice areas by infecting collateral hosts like sugarcane, *Digitaria*, *Setaria*, *Dinebra*, etc., Epidemiology is not clear but few assumptions are they may be in mycelial form in lesions of leaves, nodes, straw pieces or indoors in Himachal Pradesh. The seed borne inoculum is not of much consequences in India due to high soil temperature but it spread through grass host and easily sown paddy crop.

DISEASE MANAGEMENT OR CONTROL MEASURES

Breeding resistant varities.

Copper fungicides and organo mercurial fungicides can be sprayed once in seed bed, twice during tillering and twice in the neck emergence stage. Antibiotics such as Cepholothecin, Imotocidin, Antimycin A, Blasticidin, Kasumin and Blastimycin are effective against blast disease.

5. Red Rot of Sugarcane:

The disease is prevalent in most of the sugarcane growing areas of the world in moderate to most destructive form. First describe in Java as Red smut and spread on to USA, Australia, India and Hawaii. The disease is common in sugarcane growing areas of India and appeared as epidemic in U.P. and Bihar.

HOST: *Saccharum officinarum* L.

SYMPTOMS:

The symptoms are difficult to recognize in early but later visible on and inside stem and also on leaf.

On Stem:

In early stage of disease development, the affected green stem shows purplish colouration on rind. During the later part of rainy season or still later, the root primordia at the nodal region tends to convert into black dots, the acervuli. The infected plant shows the death of 3rd or 4th leaves and the entire crown becomes dry in severe attack.

Inside Stem:

The split open diseased stock shows red rot symptom of internal tissues. The infected tissue becomes dull red and interrupted by transverse white patches (Fig. 5.38A-C). The rind becomes shrunken during harvest with longitudinal cavity filled with profused mycelial growth.

On Leaf:

The symptom on leaf appears as elongated bright red lesions on the midrib of leaf blade and reddish patches on leaf sheath (Fig. 5.39). The lesions gradually spread throughout the length of midrib. The bright red lesion gradually changed with grayish centre, surrounded by dark reddish-brown margin. The margin become occupied by black dots, the acervuli of the fungus.

CAUSAL ORGANISM:

The causal organism i.e., the pathogen is *Colletotrichum falcatum* went. [Its Perfect stage is *Glomerella tucumanensis*].

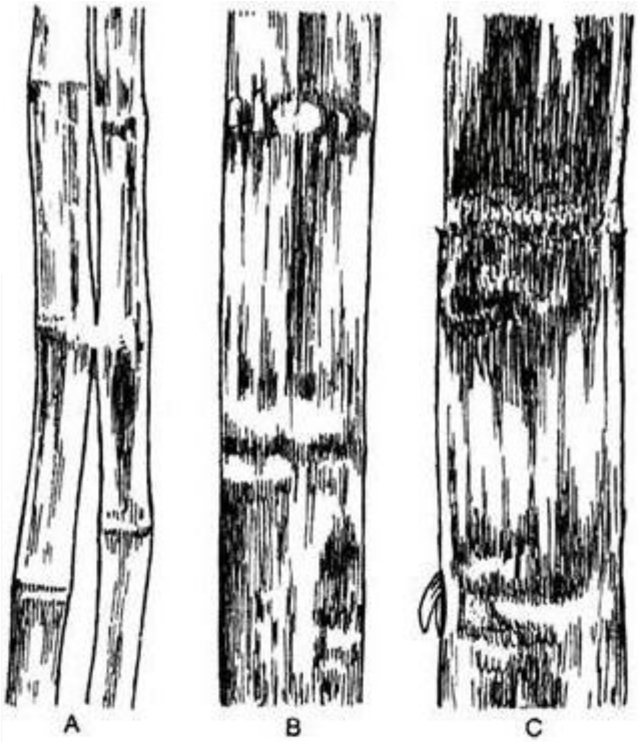
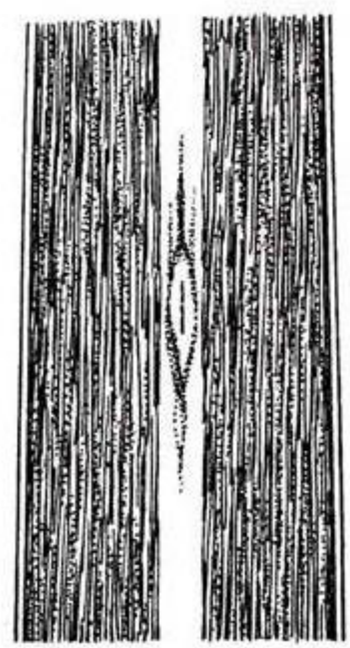


Fig. 5.38 : Red rot of sugarcane : A. Dry, shrivelled cane due to pathogenic attack, B and C. Reddening (black in figure) of the pith with white transverse blotches

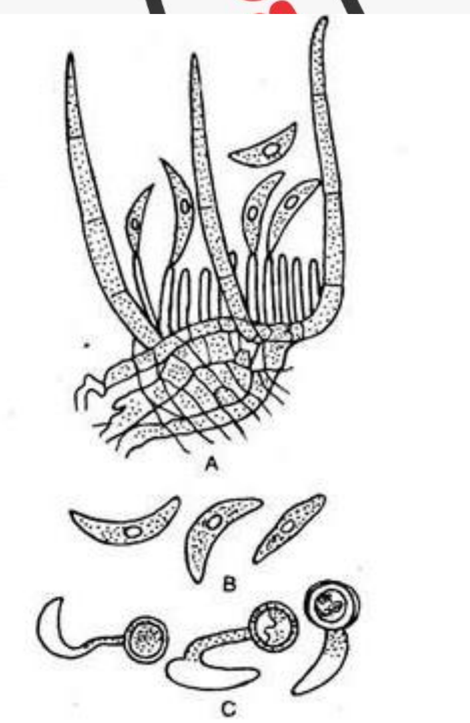


5.39 : Red rot of sugarcane : Portion of a leaf showing symptom on midrib

The fungus consists of septate, prostate much branched, thin-walled, hyaline hyphae growing intercellularly. In nutrient-deficient condition, the germ tube develops appresorium at its tip in contact with hard surface like on host and also in culture medium. The appresoria are round, oval or irregular in shape, smooth, thick-walled and brown in colour. The mycelium also develops thick- walled, round chlamydospores in old culture and also on host surface. The chlamydospores are the resting structures, and on germination they develop mycelium.

Conidia develop on hyphal tip and also inside the acervuli. The acervulus consists of a mass of short, closely packed conidiophores with numerous dark brown setae (Fig. 5.40A). The setae are also able to develop conidia-like conidiophores. The conidia are unicellular, hyaline, generally fulcate or sickle-shaped, with one end rounded and the other end pointed (Fig. 5.40B).

The sexual stage of the pathogen i.e., the perithecial stage has been reported from different countries like Australia, Brazil, China, India and Taiwan.



5.40 : Red rot of sugarcane (c.o. *Colletotrichum falcatum*) : A. Acervulus, B. Conidia and C. Germination of conidia

The perithecia remain embedded inside the host tissue except the projected ostiole. They are Globose. Perthecia contain numerous hyaline asci that are intermingled with numerous hyaline paraphyses. The asci are hyaline, clavate containing 8 ascospores. Ascospores are unicellular, hyaline and straight or slightly fusoid.

DISEASE CYCLE (fig. 5.41):

Pathogen can perpetuate in infected seed sets, in soil, plant debris and collateral hosts. Inoculum is present in the form of conidia, setae, chlamydospores, appresoria, thick walled hyphae and ascospores.

The seed sets of diseased plant are the main source of primary inoculum. The infected seed sets have inoculum inside the host tissue or have dormant mycelium in the bud scales, leaf scars etc. These seed sets invariably developed infected shoots. The acervuli developed on the infected plants produce conidia that are transmitted commonly through irrigation or rain water and rarely by wind and cause further infection.

The inoculum from soil also infects the propagating stock and gradually the young plants. The infected plants develop acervulus on root primordia at nodes and also on leaves. The conidia developed from both the sources are dispersed by rain water or by wind and cause further infection.

The pathogen may survive in soil in the form of chlamydospores, setae, appresoria and also by thick-walled hyphae and causes further infection to the next crop, where there is a gap between the harvesting and next planting. But, the pathogen may remain within the host, where the crops are available in the field round the year.

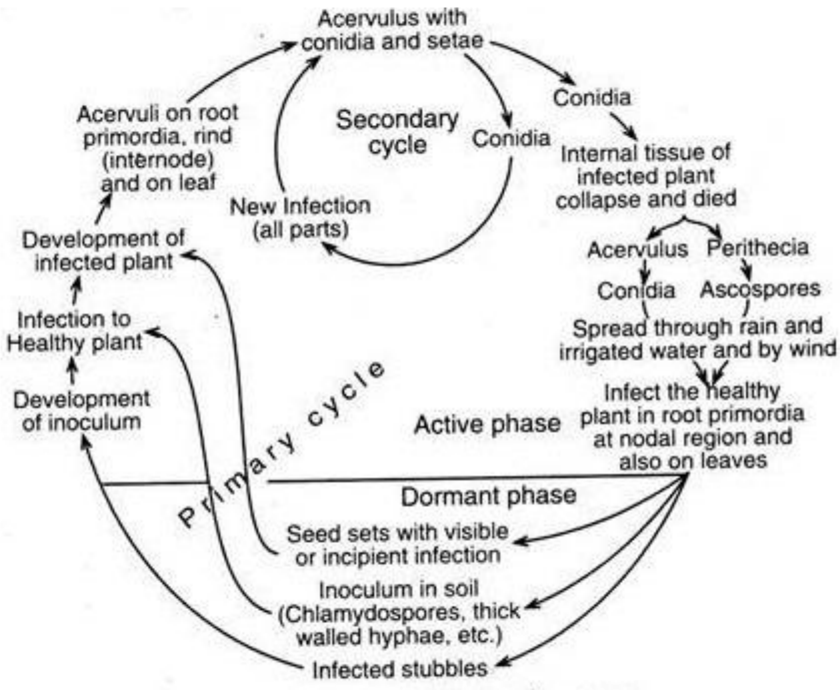


Fig. 5.41 : Disease cycle of Red rot of sugarcane

The perithecia are not common in India, but play a significant role when present.

Collateral hosts, like *Sorghum halepense*, *S. vulgare*, *Saccharum spontaneum*, *Leptochloa fiiliformis* etc., serve a significant role in annual recurrence of disease.

DISEASE MANAGEMENT:

The disease can be controlled or reduced by the following methods:

A. Cultural Methods:

These include field sanitation, selection of seed sets, crop rotation and proper drainage in the field.

1. Field Sanitation:

The field should be free from previous year's infected plant debris to reduce the primary source of inoculum.

2. Selection of Seed Sets:

The seed sets should be selected from healthy and vigorously growing plants.

3. Crop Rotation:

A long term rotation for 2-3 years help in eliminating the pathogen.

4. Proper Drainage:

Water-logging in the field increases disease incidence, so proper drainage is essential to reduce the disease incidence.

B. Physical Methods:

Heat treatment is effective to reduce the disease incidence:

1. Hot Water Treatment:

Seed sets are treated with hot water at 52°C for 18 minutes, to reduce the disease.

2. Hot Air Treatment:

Hot air at 54°C for 8 hours is found very effective to control the disease.

C. Chemical Methods:

Fungicides like Dithane Z-78, Blitox-50 and Carbendazim (0.1%) are used on standing crop and are found very effective to control the disease incidence.

D. Disease Tolerant Varieties:

The following disease tolerant varieties are recommended to cultivate — Co449, Co658, Col 158, Co1336, CoC671, CoL9 etc.

A brief account of Biopesticides:

Bio-pesticides are those biological agents or their products that are used for control of weeds, insects and pathogens.

Bio-pesticides are of two types: bio-herbicides and bio-insecticides.

(i) Bio-herbicides:
An organism which controls or destroys unwanted plants growth without harming the useful plant is called bioherbicide. The first bioherbicide happened to be mycoherbicide. It was put to use in 1981. The herbicide is *Phytophthora palmivora*. The fungus does not allow the Milkweed Vine to grow in *Citrus* orchards. Growth of *Eichhornia crassipes* (Water Hyacinth) is being controlled by *Cercospora rodmanii* in USA and *Alternaria eichhorniae* in India.

(ii) Bio-insecticides:
Bio-insecticides are those biological agents that are used to control harmful insects. They include the following.

(a) Predators:
Destructive insects or plant pests can be brought under control through introduction of their natural predators. The predators should be specific and unable to harm the useful insects. Introduction of ladybugs (Lady Bird Beetles) and Praying Mantis has been successful in combating scale insects or aphids which feed on plant sap.

(b) Parasites and Pathogens:
This is alternate biological control of plant pests through the search of their natural parasites and pathogens. They include viruses, bacteria, fungi and insect parasitoids. Parasitoids are organisms that live as parasites for some time (as early or larval stage) and free living at other times, e.g., *Trichogramma*. *Nucleopolyhedrovirus* (NPV) are species specific.

For example, *Baculovirus heliothis* (a virus) can control Cotton bollworm (*Heliothis Zea*). Similarly, *Bacillus thuringenesis* (a bacterium) is effective against the cabbage looper (*Trichoplausiani*) and *Entomophthora ignobilis* (a fungus) the green peach aphid of Potato (*Myzus persicae*).

Bacillus thuringiensis as a bio-control agent

Most important example is the soil bacterium, *Bacillus thuringiensis* (Bt). Spores of this bacterium possess the insecticidal Cry protein. Therefore, spores of this bacterium kill larvae of certain insects. The commercial preparations of *B. thuringiensis* contain a mixture of spores, Cry protein and an inert carrier. This bacterium was the first bio-pesticide to be used on a commercial scale in the world, and is the first bio-pesticide being produced on a commercial scale in India.

Thurioside is a toxin produced by bacterium *Bacillus thuringiensis*. The toxin is highly effective against different groups of insects like moths, flies, mosquitoes and beetles. It does not cause any adverse environmental pollution or disturbance. Thurioside occurs as crystals in the bacterium. It kills the susceptible insects through inhibiting ion transport in the midgut, formation of pores in gut epithelium, swelling and bursting of cells,

Transgenic Plants. They are crop plants which are modified through genetic engineering to develop natural resistance to insects by inserting cry genes of *Bacillus thuringiensis* into them, e.g., Bt Cotton. Similarly, transgenic Tomato has been developed which is resistant to homworm larvae.

With the help of recombinant DNA technology, the gene having insecticidal properties of *Bacillus thuringiensis* has been transferred to the crops plans like tomato in 1987, with the help of bacterium, *Agrobacterium tumifaciens*. Later, similar success has been achieved in different crop plants like tobacco, cotton etc., by using the similar technique. Now-a-days, Bt cotton is very popular among the farmers.

In USA, different registered formulations prepared from *B. thuringiensis* are used to control pests of different crops like Alfalfa caterpillar (Alfalfa), Bollworm (Cotton), Cabbage worm (Cabbage and Cauliflower). Orange dog (Orange), Crape leaf folder (Grapes) etc.

Trichoderma: A bio-control agent for management of soil born diseases

Trichoderma is a very effective biological mean for plant disease management especially the soil born. It is a free-living fungus which is common in soil and root ecosystems. It is highly interactive in root, soil and foliar environments. It reduces growth, survival or infections caused by pathogens by different mechanisms like competition, antibiosis, antagonism, mycoparasitism, hyphal interactions, and enzyme secretion. It excretes the enzymes like viridin, and gleotoxin there by enhance the root growth. Hence it has got significant importance in ecofriendly disease management as biopesticide.

Disease Control: *Trichoderma* is a potent biocontrol agent and used extensively for soil born diseases. It has been used successfully against pathogenic fungi belonging to various genera, viz. *Fusarium*, *Phytopthera*, *Scelerotia* etc.

Biochemical Elicitors of Disease: *Trichoderma* strains are known to induce resistance in plants. Three classes of compounds that are produced by *Trichoderma* and induce resistance in plants are now known. These compounds induce ethylene production, hypersensitive responses and other defense related reactions in plant cultivars.

Transgenic Plants: Introduction of endochitinase gene from *Trichoderma* into plants such as tobacco and potato plants has increased their resistance to fungal growth. Selected transgenic lines are highly tolerant to foliar pathogens such as *Alternaria alternata*, *A. solani*, and *Botrytis cirerea* as well as to the soil-borne pathogen, *Rhizectonia* spp.

Biocontrol mechanisms of *Trichoderma*:

The *Trichoderma* may suppress the growth of the pathogen population in the rhizosphere through competition and thus reduce disease development. It produces antibiotics and toxins such as trichothecin and a sesquiterpine, Trichodermin, which have a direct effect on other organisms. The antagonist (*Trichoderma*) hyphae either grow along the host hyphae or coil around it and secrete different lytic enzymes such as chitinase, glucanase and pectinase that are involved in the process of mycoparasitism. Examples of such interactions are *T. harzianum* acting against *Fusarium oxyporum*, *F. roseum*, *F. solani*, *Phytophthara colocaciae* and *Sclerotium rolfsii*. In addition, Trichoderma Enhances yield along with quality of produce. Boost germination rate. Increase in shoot & Root length Solubilizing various insoluble forms of Phosphates Augment Nitrogen fixing. Promote healthy growth in early stages of crop. Increase Dry matter Production substantially. Provide natural long term immunity to crops and soil.

***Trichoderma* formulations:**

Important commercial formulations are available in the name of Sanjibani, Guard, Niprot and Bioderma. These formulations contain 3x106 cfu per 1 g of carrier material. Talc is used as carrier for making powder formulation.

Uses:

Used in Damping off caused by *Pythium* sp. *Phytophthora* sp., Root rot caused by *Pellicularis filamentosa*, Seedling blight caused by *Pythium*, Collar rot caused by *Pellicularia rolfsii*, Dry rot caused by *Macrophomina phaseoli*, Charcoal rot caused by *Macrophomina phaseoli*, Loose smut caused by Ustilago segetum, Karnal bunt diseases, Black scurf caused by *Rhizoctonia solani*, Foot rots of Pepper and betel vine and Capsule rot of several crops. Effective against silver leaf on plum, peach & nectarine, Dutch elm disease on elm's honey fungus (*Armillaria mellea*) on a range of tree species, Botrytis caused by *Botrytis cinerea*, Effective against rots on a wide range of crops, caused by *fusarium*, *Rhizoctonia*, and *pythium*, and sclerotium forming pathogens such as *Sclerotinia* & *Sclerotium*

Recommended For:

Trichoderma is most useful for all types of Plants and Vegetables such as cauliflower, cotton, tobacco, soybean, sugarcane, sugarbeet, eggplant, red gram, Bengal gram, banana, tomato, chillies, potato, citrus, onion, groundnut, peas, sunflower, brinjal, coffee, tea, ginger, turmeric, pepper, betel vine, cardamom etc.

(c) Natural Insecticides:

They are insecticides and related pesticides which are obtained from microbes and plants. A number of natural insecticides are available. The common ones include

Neem as Bio-pesticide

The importance of Margosa or Neem (*Azadirachta indica*) as bio-pesticide was realized by the modern scientific community, as early as 1959, when a German scientist in Sudan found that neem was the only tree that remained green during a desert locust plague. Literatures confirm that neem can effectively get rid of over 200 pest species that affects plants. The pesticidal characteristics of neem is largely attributable to Azadirachtin found in the neem extracts which is a growth regulator and as well as a powerful feeding and ovipositional deterrent. Azadirachtin is non-volatile and an insect cannot prevent it by smell but has to taste it, in order to respond to it. A taste of azadirachtin stimulates at least one 'deterrent neuron' in insects which show an anti-feedant response. The strength of 'deterrent neuron' responses has been correlated with the strength of anti-feedant responses. Neem oil can also suffocate mites, whiteflies, aphids and other types of soft bodied insects on contact. So it is clear that neem does not kill on contact, rather it inhibits feeding and reproduction of the pests. These multiple modes of action make it unlikely that insects and plant pathogens can develop resistance to neem. Also certain pest such as floral thrips, diamond back moth and several leaf miners which develop resistance to the inorganic pesticides or that are inherently difficult to control with conventional pesticides are effectively controlled or managed with neem. Spray of the same keeps away the Japanese beetles and other leaf eating pests because of the antifeedant property of azadirachtin.

The emulsifiable concentrate (EC) of Neem prepared mostly from the Neem oil is used as the pesticide of choice in organic agriculture. It belongs to the category of medium to broad spectrum pesticides. Among the other known botanical pesticides such as Rotenone and Pyrethrins, neem is found to be superior due to a number of reasons. It is also compatible with a list of other synthetic pesticides, which enables its usage as a component of Integration pest management (IPM). Below are the reasons to explain why neem seems to be best and non-replacable component of IPM

- Neem pesticide is a natural product, absolutely non toxic, 100% biodegradable and eco friendly.
- It is suited for mixing with other synthetic pesticide and in fact enhances their action.
- None or lesser quantity of synthetic pesticides needs to be used, thereby reducing the environmental load.
- Several synthetic pesticides being single chemical compounds cause easy development of resistant species of pests. Neem consists of several compounds hence development of resistance is impossible.
- Neem does not destroy natural predators and parasites of pests thereby allowing these natural enemies to keep a check on the pest population.
- Neem also has systemic action and seedlings can absorb and accumulate the neem compounds to make the whole plant pest resistant.
- Neem has a broad spectrum of action active on more than 200 species of pests.
- Neem is harmless to non target and beneficial organisms like pollinators, honey bees, mammals and other vertebrates.

BRYOPHYTES

INTRODUCTION

Bryophytes are chlorophyllous, autotrophic, embryophytic, atracheophytic, archegoniate and amphibious cryptogams which show invariable heteromorphic alternation of generations in their haplodiplontic life cycle. The division Bryophyta (Gr. bryon=moss) includes over 960 genera and 25000 species of non-vascular embryophytes such as mosses, liverworts and hornworts. The fossil record indicates that bryophytes evolved on earth about 395 – 430 million years ago (i.e. during Silurian period of Paleozoic era). The study of bryophytes is called bryology. Hedwig is called 'Father of Bryology'. Shiv Ram Kashyap is the 'Father of Indian Bryology'.

GENERAL CHARACTERS OF BRYOPHYTES

1. Bryophytes are small (2cm to 60cm) primitive land plants that grow on moist shady places. They prefer moist, cool and shady places to grow. Few of them grow in water and others in bogs, moist walls, rocks and tree trunks.
2. Though they started land life, they require presence of water to complete their life cycle for movement of motile male gametes (antherozoids).
3. They are predominantly amphibious in nature, hence called "amphibians of the plant kingdom"
4. Bryophytes show "heteromorphic alternation of generations". The gametophytic and sporophytic generations alternate with each other regularly in the life cycle. In this the haploid plant body is gametophyte and it is dominant phase. Diploid sporophyte is physically and nutritionally dependent on the gametophyte.
5. In primitive bryophytes the gametophyte is dorsoventral, dichotomously branched green prostrate structure. In few advanced forms gametophyte is differentiated into stem, leaves and rhizoids.
6. Bryophytes are autophytes and lead autotrophic mode of nutrition.
7. Bryophytes lack true roots. In primitive forms there are unicellular rhizoids, while in advanced forms the rhizoids are branched and multicellular. These rhizoids help in anchorage and absorption.
8. The entire thallus is leaf like in primitive bryophytes while in advanced forms leaves are spirally arranged and are called microphyll. The microphyll is a small leaf with median midrib.
9. The plant body of bryophytes consists of simple parenchymatous tissue with NO vascular tissues like xylem and phloem.
10. Bryophytes reproduce vegetatively with the help of tubers, bulbils, protonemal branches, fragmentation etc.
11. Sexual reproduction is oogamous type. The sex organs of bryophytes are called gametangia. Gametangia are multicellular with sterile jacket. Female gametangium is known as archegonium and male gametangium is known as antheridium.
12. Antheridium is club shaped. It shows a basal stalk and a dome shaped body. The body is covered by jacket enclosing androcytes which develop spermatozoids. Spermatozoids are small, slender and bicilate.
13. Archegonium is flask shaped. It has a basal small stalk, median swollen venter and a terminal long neck. On the bod axis archegonium has axial row of neck cells, ventral canal cell and egg. The venter wall enlarges with the developing embryo to form protective envelop called calyptra.
14. Fertilization is possible in the presence of water. The egg is fertilized by the actively swimming motile spermatozoids while it is still within the archegonium.
15. The fertilized zygote develops into sporophyte. Sporophyte is diploid, multicellular and not well defined. Sporophyte has a distinct foot, seta and capsule. Sporophyte remains attached to the gametophyte throughout its life and is dependent on it. Reduction division takes place in the developing sporophyte which results in the formation of haploid spores. All the spores produced in a sporophyte are morphologically alike.
16. Life cycle of bryophytes is haplodiplontic with heteromorphic alternation of generation of multicellular generations.

DISTRIBUTION OF BRYOPHYTES:

Bryophytes are represented by 960 genera and 25,000 species. They are cosmopolitan in distribution and are found growing from polar, alpine to both in the temperate and tropical regions of the world at an altitude from sea level to 20000 feet. Bryophytes do not live in extremely arid sites or in seawater, although some are found in perennially damp environments within arid regions and a few are found on seashores above the intertidal zone. A few bryophytes are aquatic. The greatest diversity is at tropical and subtropical latitudes.

In India, Bryophytes are quite abundant in both Nilgiri hills and Himalayas; Kullu, Manali, Shimla, Darjeeling, Dalhousie and Garhwal are some of the hilly regions which also have a luxuriant growth of Bryophytes. Eastern Himalayas have the richest in bryophytic flora. A few species of *Riccia*, *Marchantia* and *Funaria* occur in the plains of U.P, M.P, Rajasthan, Gujarat and South India.

In hills they grow during the summer or rainy season. Winter is the rest period. In the plains the rest period is summer, whereas active growth takes place during the winter and the rainy season.

REPRODUCTION IN BRYOPHYTES:

Bryophytes reproduce by vegetative and sexual methods.

Vegetative Reproduction in Bryophytes:

Bryophytes possess a characteristic feature and that is their tendency towards extensive vegetative reproduction. The vegetative reproduction takes place in favourable season for vegetative growth. Majority of the Bryophytes propagate vegetatively.

Some important methods of vegetative reproduction are as follows:

1. By death and decay of the older portion of the thallus or fragmentation.
2. By persistent apices.
3. By tubers.
4. By gemmae.
5. By adventitious branches.
6. By Regeneration.
7. By innovation.
8. By primary protonema.
9. By secondary protonema.
10. By bulbils.
11. By apospory.
12. By cladia.
13. By separation of whole shoots.
14. By separation of shoot tips.
15. By rhizoidal tips.

1. By Death and Decay of the Older Portion of Thallus or by Fragmentation:

In Bryophytes the growing point is situated at the tip of the thallus. The basal, posterior or older portion of the thallus starts rotting or disintegrating due to ageing or drought and the lobes get separated and develop into independent plants by apical growth.

2. By Persistent Apices:

Due to prolonged dry or summer or towards the end of growing season the whole thallus dries and get destroyed except the growing point. Later, it grows deep into the soil and becomes thick. Under favorable conditions it develops into a new thallus.

3. By Tubers:

Tubers are formed in desiccating (drying effect of the air) species. The subterranean branches get swollen at their tips and on its periphery are two to three layers of water proof corky, hyaline cells develop. These layers surround the inner cells which contain starch, oil globules and albuminous layers. During the unfavorable conditions the thallus dies out but the dormant tubers remain unaffected. On getting the favourable conditions each tuber germinates to form a new plant.

4. By Gemmae:

Gemmae are green, multicellular reproductive bodies of various shapes. These are produced in gemma cups, on the surface of the leaves, on stem apex or even inside the cells. They get detached from the parent plant and after falling on a suitable substratum gemmae give rise to a new individual directly or indirectly.

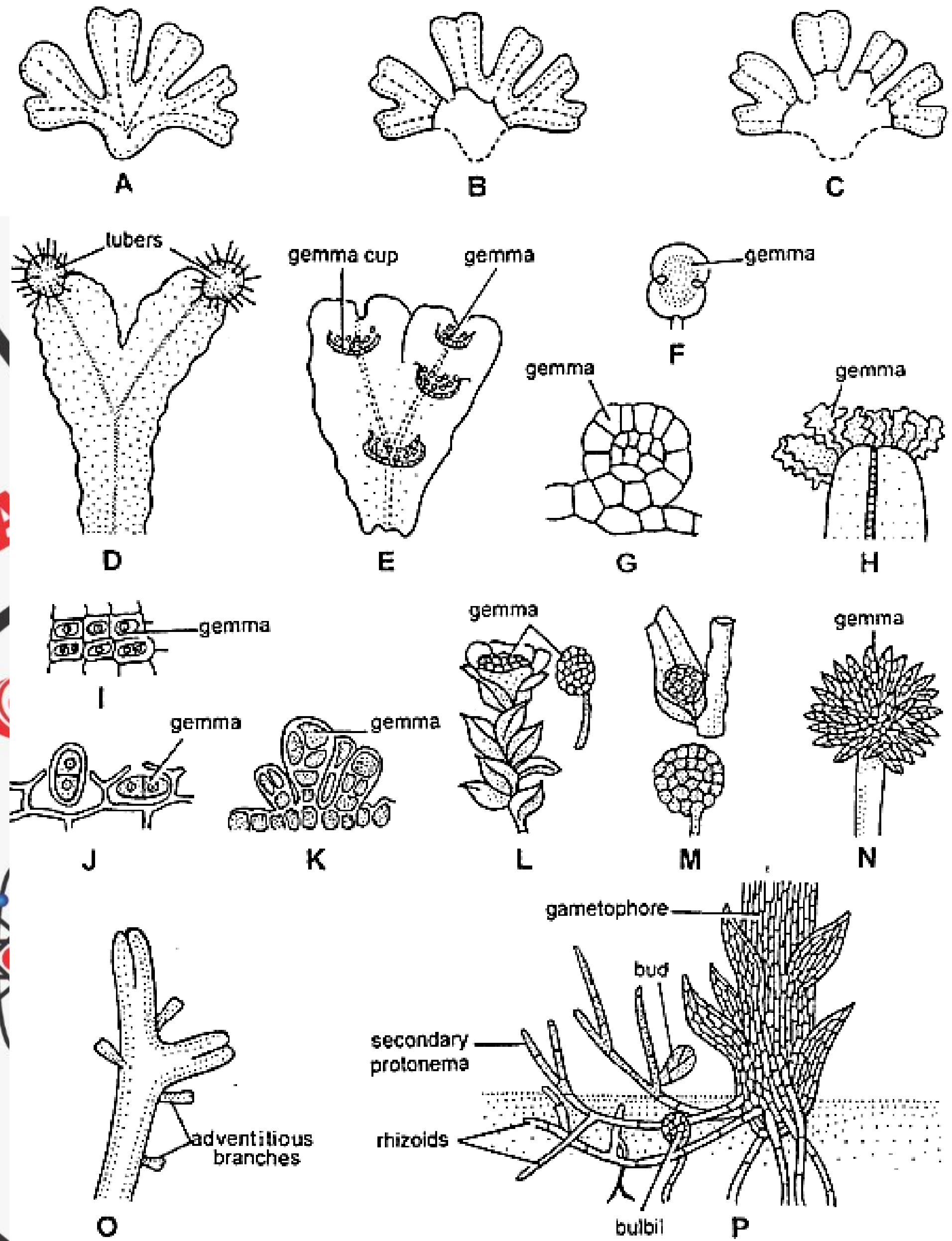


Fig. 1. (A–P). Vegetative reproduction in Bryophytes.

5. By Adventitious Branches:

The adventitious branches develop from the ventral surface the thallus and on detachment develops into new thalli.

6. By Regeneration:

The liverworts possess an amazing power of regeneration. Part of the plant or any living cell of the thallus (e.g., rhizoid, scales) are capable of regenerating the entire plant

7. By Innovation:

In Sphagnum one of the branches in the apical cluster develop more vigorously and continues the growth upwards. This long upright branch has all the characteristics of main axis. It is called innovation. Due to progressive death and decay of the parent plant these innovation become separated and establish as new plants.

8. By Primary Protonema:

Primary protonema is the filamentous produced by spores of the mosses. It produces the leafy gametophores. It breaks into short filament by the death of cells at intervals. Each detached fragment grows into a new protonema.

9. By Secondary Protonema:

The protonema formed by other methods than from the germination of spores is called secondary protonema. It may develop from any living cells of the leafy gametophore i.e., from leaf, stem, rhizome, injured portion, antheridium, paraphysis or archegonium. From this arise the leafy gametophores or lateral buds.

10. By Bulbils:

These are small resting buds develop on rhizoids. Bulbils are full of starch and germinate into a protonema which bears leafy gametophores.

11. By Apospory:

The production of diploid gametophyte from the unspecialized sporophyte without meiosis is known as apospory.

12. By Cladia:

These are the small or broad detachable branches from leaf (Leaf cladia) or (Stem cladia).

13. By Separation of Whole Shoots:

A number of catkins like deciduous branches develop over the entire surface of the gametophyte. On separation these branches develop into new plant.

14. By Separation of Shoot Tips:

The separated shoot tips develop into new plant.

15. By Rhizoidal Tips:

The apical part of the young rhizoids divide and re-divide to form a gemma like mass of cells. These cells contain chloroplast and are capable to develop into new thallus.

Sexual Reproduction:

1. Sexual reproduction is highly oogamous.
2. Male and female sex organs are known as antheridia (Sing, antheridium) and archegonia (Sing, archegonium), respectively. Both kinds of sex organs may be developed on the same individual or on different plants.
3. Sex organs are multicellular and jacketed.
4. Antheridium is stalked attached to gametophyte or embedded within it. It may be club, ellipsoid, pear shaped or oblong and has an outer one cell thick jacket which encloses a mass of squarish or cuboidal fertile cells called androcytes. Each androcyte metamorphoses into biflagellate antherozoid or spermatozoid or sperm (male gamete). Each sperm is motile, minute, slender, spirally curved with two long, terminal, whiplash flagella.
5. Archegonium: Appears for the first time in plant kingdom and exist till gymnosperms. It is stalked, flask shaped structure. It has a basal sac like, swollen portion called venter and an upper elongated, slender neck. The neck is filled with many neck canal cells whereas venter has a large egg cell and a small venter canal cell. Venter is attached to or often deeply embedded in gametophyte. Single layer of sterile jacket cells around neck and one or more layered around venter. Neck is usually projected or freely exposed to be accessible to sperms.

Fertilization:

6. The mature antheridium dehisces and releases antherozoids. They swim in the film of water (essential for fertilization) and are attracted towards the neck of the archegonium chemotactically by certain substances (like sugars, malic acid, proteins, inorganic salts of potassium etc.) present in the mucilaginous substance formed by the degeneration of neck canal cells and venter canal cell in mature archegonium.
7. Tip of archegonium opens and a narrow canal opening to exterior is formed acting as passage way to egg. Liberated sperms reach archegonia and enter through open neck and canal to reach venter. First on the sperms penetrate the egg and fuses with female nucleus to complete fertilization. This ends the gametophytic generation and starts sporophytic generation. It is retained within the venter of the archegonium.

Sporophyte:

1. It is a second phase where the fertilized egg starts secreting cellulose wall around it. It contains chromatin material of male and female.
2. Without resting period, the zygote undergoes repeated divisions to form a multicellular structure called the embryo.
3. The first division of the zygote is always transverse and the outer cell develops into embryo. Such an embryogeny is called exoscopic.
4. Embryo is a multicellular, undifferentiated mass of cells which develops into a sporophyte or sporogonium by obtaining nourishment from parent gametophyte. It is ephemeral.
5. The embryo by further segmentation and differentiation finally develops into a full-fledged leafless and rootless sporophyte. Sporophyte is usually differentiated into foot, seta and capsule. In certain cases it is represented only by capsule or by foot and capsule.
6. Sporophyte is attached to parent gametophytic plant body throughout its life. It partially or completely depends on it for nutrition.
7. Foot is basal, bulbous structure. It is embedded in the tissue of gametophyte. It absorbs the food material from the gametophyte.
8. Seta is present between the foot and capsule. It elongates and pushes the capsule through protective layers. It also conducts the food to the capsule absorbed by foot.

9. Capsule is the terminal part of the sporogonium producing sporogenous tissue which develops entirely into spore mother cells or differentiated into spore mother cells and elater mother.
10. Spore mother cells undergo meiotic diagonal division to produce asexually four haploid spores or meiospores or gonospores which are arranged in tetrahedral tetrads.
11. All Bryophytes are homosporous i.e., all spores are similar in shape, size and structure.
12. Elater mother cells develop into elaters or pseudo elaters which are hygroscopic in nature. Elaters are present in liverworts and absent in mosses which helps in dispersal of spores to a distant places.
13. Venter wall enlarges with the developing sporogonium and forms a protective multicellular layer called calyptra (gametophytic tissue enclosing the sporophyte).

Young Gametophyte:

1. The meiospore (spore formed after meiosis) is the first cell of the gametophytic phase.
2. Each spore is unicellular, haploid and germinates into young gametophytic plant or first germinates into a filamentous protonema on which buds are produced to give rise to a young gametophytic plant.

Classification of Bryophytes

The term bryophytes was first time used by R. Braun (1864), who included algae, fungi, lichens and mosses in this group. In later systems of classification, however, algae, fungi and lichens were placed in a separate division thallophyta, and liverworts and mosses together in bryophytes.

Eichler, way back in 1813, had recognized two classes in division bryophytes;
i. Hepaticae (liverworts) ii. Musci (mosses)

Takhtajan (1953) recognized three classes in bryophytes:
i. Hepaticae (liverworts) ii. Anthocerotae (hornworts) iii. Musci (mosses)

Rothmaler (1957) changed nomenclature of three classes of bryophytes as under:

i. Hepaticae → Hepaticopsida ii. Anthocerotae → Anthocerotopsida iii. Musci → Bryopsida

International code of Botanical Nomenclature (ICBN) suggested in 1956 that the suffix-opsida should be used for the classes and such usage had already been proposed by Rothmaler (1951) for the classes of Bryophytes.

1. **Class – Hepaticopsida [Hepaticae (liverworts)]**
   - o Order – Sphaerocarpales Ex: *Sphaerocarpus*
   - o Order – Marchantiales – *Marchantia*
   - o Order – Metzgeriales – *Pellia, Metzgaria*
   - o Order – Jungermanniales – *Porella, Frullania*
   - o Order – Calobryales - *Calobryum*
   - o Order – Takakiales – *Takakia*
2. **Class – Anthocerotopsida [Anthocerotae (hornworts)]**
   - o Order – Anthocerotales – *Anthoceros*
3. **Class – Bryopsida [Musci (mosses)]** has 3 subclasses
   - **I. Sphagnobrya**
     - o Order – Sphagnales – *Sphagnum*
   - **II. Andreaeobrya**
     - o Order – Andreaeales – *Andreaea*
   - **III. Eubrya (True mosses)** has 3 cohorts & 15 orders
     - o Order – Bryales – *Funaria*
     - o Order – Polytrichales – *Polytrichum*

Alternation of generations in the life-cycle of a bryophyte

The life-cycle of a bryophyte shows regular alternation of gametophytic and sporophytic generations. This process of alternation of generations was demonstrated for the first time in 1851 by Hofmeister. Thereafter in 1894 Strasburger could actually show the periodic doubling and halving of the number of chromosomes during the life-cycle.

The haploid phase (n) is the gametophyte or sexual generation. It bears the sexual reproductive organs which produce gametes, i.e., antherozoids and eggs. With the result of gametic union a zygote is formed which develops into a sporophyte. This is the diploid phase (2n). The sporophyte produces spores which always germinate to form gametophytes.

During the formation of spores, the spore mother cells divide meiotically and haploid spores are produced. The production of the spores is the beginning of the gametophytic or haploid phase. The spores germinate and produce gametophytic or haploid phase. The spores germinate and produce gametophytes which bear sex organs.

Ultimately the gametic union takes place and zygote is resulted. It is diploid (2n). This is the beginning of the sporophytic or diploid phase. This way, the sporophyte generation intervenes between fertilization (syngamy) and meiosis (reduction division); and gametophyte generation intervenes between meiosis and fertilization.

In bryophytes, where the two generations are morphologically different, the type of alternation of generations is known as heteromorphic.

In the case of bryophytes the gametophyte generation is conspicuous and longer-lived phase of the life-cycle in comparison to that of sporophyte generation. Here, the gametophyte is quite independent whereas the sporophyte is dependent somehow or other on the gametophyte for its nutritive supply. The gametophyte gives rise to sporophyte and sporophyte to the gametophyte and thus there is regular alternation of generations.

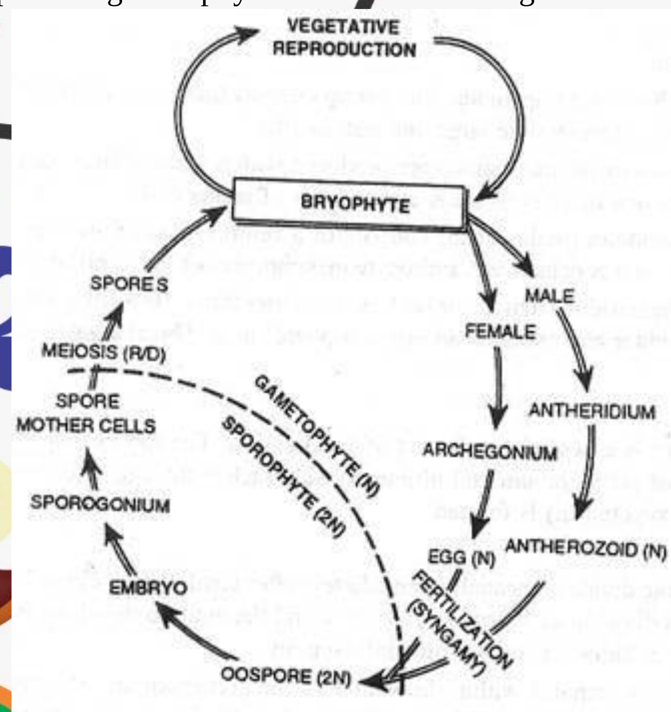


Fig. 19.1. Bryophyte. Typical graphic life-cycle.

Marchantia

Systematic Position of *Marchantia*:

Division	:	Bryophyta
Class	:	Hepaticopsida
Order	:	Marchantiales
Family	:	Marchantiaceae
Genus	:	*Marchantia*

Distribution and Habitat of *Marchantia*:

Marchantia, is represented by about 65 species worldwide. In India, it is about 11 species. These species are commonly found growing in the Himalayan region, in plains of Haryana, Punjab, Uttar Pradesh and hilly regions of South India. Some of the common Indian species are *M. palmata*, *M. polymorpha* (wide occurrence), *M. simlana* etc. *M. polymorpha* var aquatic grows submerged in swampy meadows.

All species are terrestrial and cosmopolitan in distribution. The species prefer to grow in moist and shady places like wet open woodlands, banks of streams, wood rocks or on shaded stub rocks. These grow best after the forest fire in the burnt soil. It is perhaps because of nitrification of soil due to fire

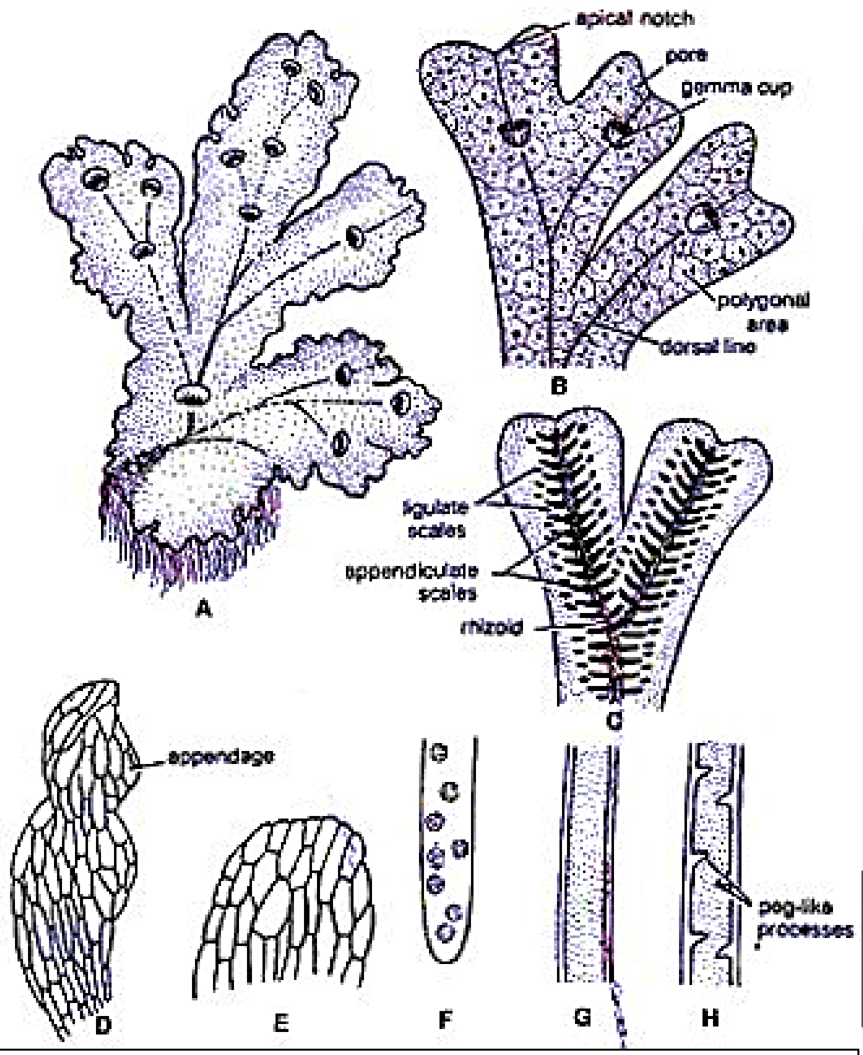


Fig.1. (A-H) *Marchantia:* Thallus structure (A) Vegetative thallus (B) Dorsal surface (C) Ventral surface (D) Appendiculate scale (E) Ligulate scale, (F) Tuberculated rhizoid (surface view), (G) Smooth walled rhizoid (H) Tuberculated rhizoid showing internal view

Gametophytic Phase of *Marchantia*:

External Features of Gametophyte:

The plant body is gametophytic, thalloid, flat, prostrate, plagiotropic, 2-10 cm. long and dichotomously branched (Fig. 1 A).

Dorsal surface: Dorsal surface is dark green with conspicuous midrib and a number of polygonal areas called areolae. The midrib is marked on the dorsal surface by a shallow groove and on the ventral surface by a low ridge. Each polygonal area represents the underlying air chamber.

The boundaries of these areas represent the walls that separate each air chamber from the next. Each air chamber has a central pore. The midrib ends in a depression at the apical region forming an apical notch in which growing point is situated (Fig. 28 B).

Dorsal surface also bears the vegetative and sexual reproductive structures. **The vegetative reproductive structures are gemma cup and develop along the midrib. These are crescent shaped with spiny or fimbriate margins** (Fig. I A, 15).

Sexual reproductive structures are borne on special Stalked structures called gametophores or gametangiophores. The gametophores bearing archegonia are called archegoniophores and that bearing antheridia are called antheridiophores (Fig. 1 A, B).

Ventral surface:

The ventral surface of the thallus bears scales and rhizoids along the midrib.

Scales are violet coloured, multicellular, one cell thick and arranged in 2-4 rows (Fig. 1 C). Scales are of two types: (i) Simple or ligulate (ii) Appendiculate.

Appendiculate (Fig- 1 C, D) scales form the inner row of the scales close with midrib. Ligulate scales form the outer or marginal row and are smaller than the appendiculate scales (Fig. 1 C, E).

Rhizoids are unicellular, branched and develop as prolongation of the lower epidermal cells. They are of two types:
(i) Smooth-walled rhizoids, (ii) Tuberculate rhizoids.
In smooth-walled rhizoids both the inner and outer wall layers are fully stretched while in tuberculate rhizoids appear like circular dots in surface view (Fig. 1 F). The inner wall layer modifies into peg like in growth which projects into the cell lumen (Fig. 1 H). The main functions of the rhizoids are to anchor the thallus on the substratum and to absorb water and mineral nutrients from the soil.

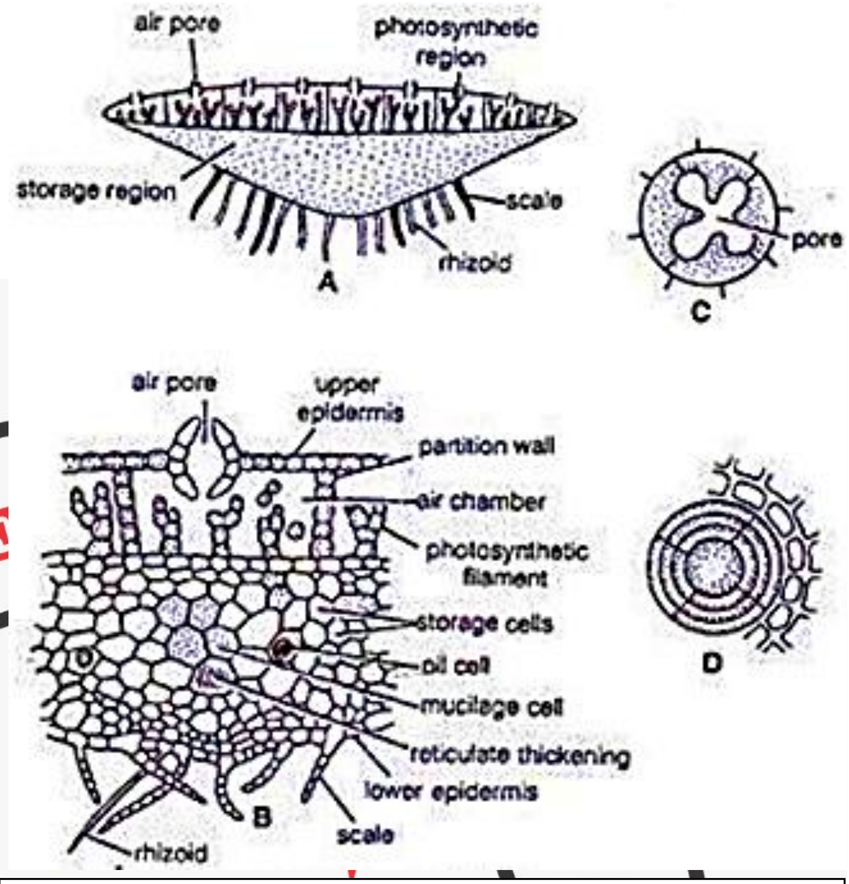


Fig.2. (A-E) *Marchantia:* Internal structure of thallus. (A) Vertical transverse section (V.T.S) of thallus (Diagrammatic) (B) V.T.S of thallus (a part cellular (C) Air pore as seen in the ventral view (D) Air pore as seen in the dorsal view

Anatomy of the Gametophyte:
A vertical cross section of the thallus can be differentiated **photosynthetic zone and lower storage zone** (Fig. 2 A- E).
Upper Photosynthetic zone:
The outermost layer is upper epidermis with thin walled square, compactly arranged cells and contain few chloroplasts. Its continuity is broken by the presence of many barrel shaped air pores. Each pore is surrounded by four to eight superimposed tiers of concentric rings. (Fig. 2 B) with three to four cells in each tier (Fig. 2 D).
Air pores are compound in nature. The lower tier consists of four cells which project in the pore and the opening of the pore looks star like in the surface view (Fig. 2 C). The walls of the air pore lie half below and half above the upper epidermis (Fig. 2 B).
Just below the upper epidermis photosynthetic chambers are present in a horizontal layer (Fig. 2 B). Each air pore opens inside the air chamber and helps in exchange of gases during photosynthesis.
These are chambers develop schizogenously (Vocalized separation of cells to form a cavity) and are separated from each other by single layered partition walls. The partition walls are two to four cells in height. Cells contain chloroplast. Many simple or branched photosynthetic filaments arise from the base of the air chambers (Fig. 2 B).
Storage zone:
It lies below the air chambers. It is more thickened in the centre and gradually tapers towards the margins. It consists of several layers of compactly arranged, thin walled parenchymatous isodiametric cells. Intercellular spaces are absent.
The cells of this zone contain starch. Some cells contain a single large oil body or filled with mucilage. The cells of the midrib region possess reticulate thickenings. The lower most cell layer of the zone forms the lower epidermis. Some cells of the middle layer of lower epidermis extend to form both types of scales and rhizoids (Fig. 2 B).

Reproduction in *Marchantia*: takes place by vegetative and sexual methods.
Vegetative Reproduction:
1. By Gemmae:
Gemmae are produced in the gemma cups which are found on the dorsal surface of the thallus (Fig. 3 A). Gemma cups are crescent shaped with smooth, spiny or fimbriate margins (Fig. 3 B).
V. S. passing through the gemma cup shows that it is well differentiated into two regions:

Upper photosynthetic region and inner storage region (Fig. 3 D). The structure of both the zones is similar to that of the thallus. **Mature gemmae are found to be attached at the base of the gemma cup by a single celled stalk. Intermingled with gemmae are many mucilage hairs. Each gemma is autotrophic, multicellular, bilaterally symmetrical, thick in the centre and thin at the apex. It consists parenchymatous cells, oil cells and rhizoidal cells. It is notched on two sides in which lies the growing point** (Fig. 3 C).

All cells of the gemma contain chloroplast except rhizoidal cells and oil cells. Rhizoidal cells are colourless and large in size. Oil cells are present just within the margins and contain oil bodies instead of chloroplast.

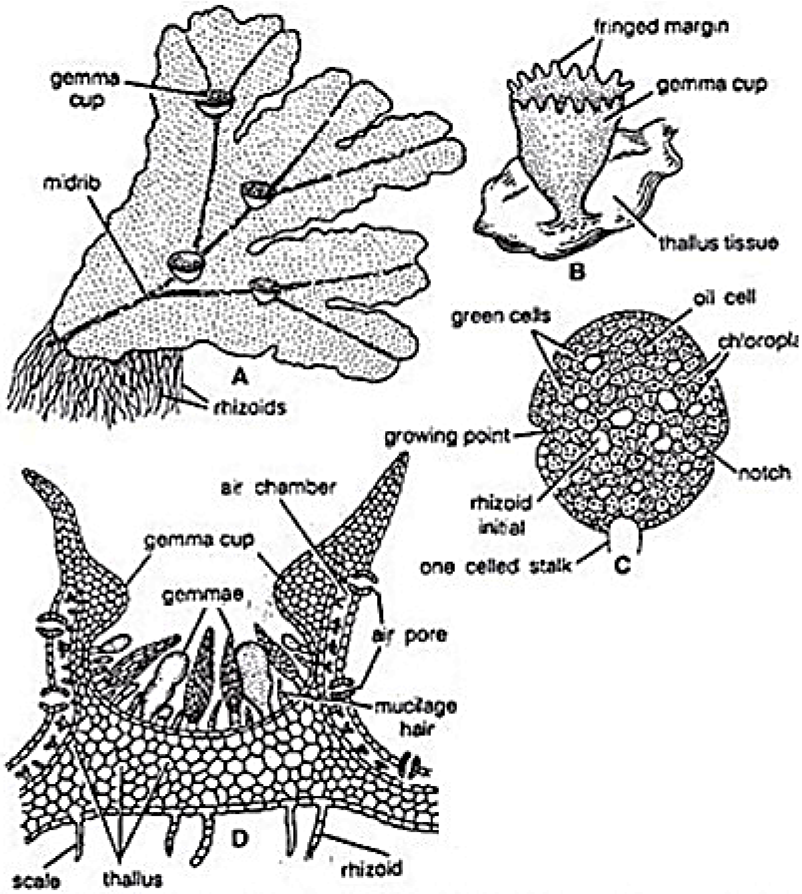


Fig.3. (A-D) *Marchantia:* Gemma cup. (A) Thallus showing gemma cup on the dorsal surface (B) A gemma cup (C) Gemma (D) Gemma cup in vertical section

Dissemination of Gemmae:

Mucilage hairs secrete mucilage on absorption of water. It swells up and presses the gemmae to get detached from the stalk in the gemma cup. They may also be detached from the stalk due to the pressure exerted by the growth of the young gemmae. The gemmae are dispersed over long distances by water currents.

Germination of Gemmae:

After falling on a suitable substratum gemmae germinate. The surface which comes in contact with the soil becomes ventral surface.

The rhizoidai cells develop into rhizoids. Meanwhile, the growing points in which lies the two lateral notches form thalli in opposite directions. Thus, from a single gemmae two thalli are formed. Gemmae which develop on the male thalli form the male plants and those on the female thalli form the female plant.

2. Death and decay of the older portion of the thallus or fragmentation:

The basal part of the thallus rots and disintegrates due to ageing. When this process reaches up to the place of dichotomy, the lobes of the thallus get separated. The detached lobes or fragments develop into independent thalli by apical growth (Fig. 4 A-C).

3. By adventitious branches:

The adventitious branches develop from any part of the thallus or the ventral surface of the thallus or rarely from the stalk and disc of the archegoniophore. On being detached, these branches develop into new thalli (Fie. 4 D).

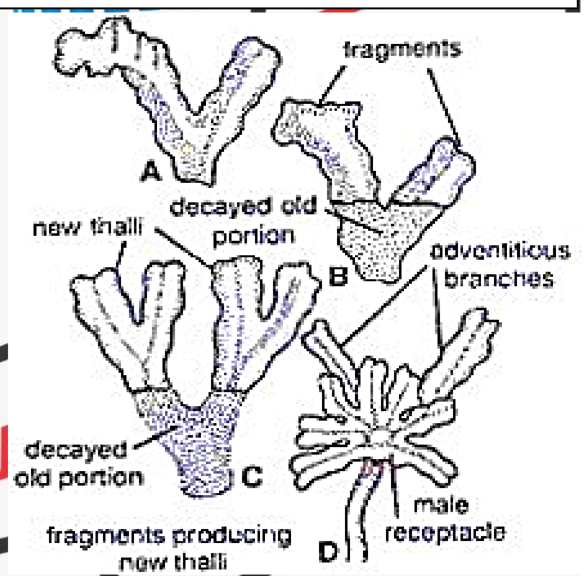


Fig.4. (A-D) *Marchantia:* Vegetative reproduction. (A-C) Fragmentation (D) Adventitious branches arising between the lobes from the lower surface of the male disc

Sexual Reproduction:

Sexual reproduction in *Marchantia* is oogamous. All species are dioecious. Male reproductive bodies are known as antheridia and female as archegonia. Antheridia and archegonia are produced on a special, erect modified lateral branches of thallus called antheridiophore and archegoniophore or carpocephalum respectively (Fig. 5 A, B).

Further growth of the thallus is checked because growing point of the thallus is utilised in the formation of these branches.

Internal structure of Antheridiophore or Archegoniophore:

Its transverse section shows that it can be differentiated into two sides: ventral side and dorsal side. Ventral side has two longitudinal rows with scales and rhizoids. These grooves, run longitudinally through the entire length of the stalk. Dorsal side shows an internal differentiation of air chambers. (Fig. 5 C).

Antheridiophore:

It consists of 1-3 centimetre long stalk and a lobed disc at the apex (Fig. 5A). The disc is usually 8 lobed. The lobed disc is a result of created dichotomies.

L.S. through disc of Antheridiophore:

The disc consists of air chambers alternating with air cavities. Air chambers are more or less triangular and open on upper surface by a pore called ostiole. Antheridia arise in acropetal succession i.e., the older near the center and youngest at the margins. (fig. 6 A).

Mature Antheridium:

A mature antheridium is globular in shape and can be differentiated into two parts stalk and body. Stalk is short multicellular and attaches the body to the base of the antheridial chamber. A single layered sterile jacket encloses the mass of androcyte mother cells which metamorphosis into antherozoids (Fig. 6 B, 7 G). The antherozoid is a minute rod like biflagellate structure (Fig. 8 H).

Development of Antheridium: (NOT FOR EXAM)

The development of the antheridium starts by a single superficial cell which is situated on the dorsal surface of the disc, 2-3 cells behind the growing point. This cell is called antheridial initial (Fig. 7 A). The antheridial initial increases in size and divides by a transverse division to form an outer upper cell and a lower basal cell (Fig. 7 B).

Basal cell remains embedded in the tissue of the thallus, undergoes a little further development and forms the embedded portion of the antheridial stalk. Outer cell divides to form a filament of four cells. Upper two cells of the four celled filament are known as primary antheridial cells and lower two cells are known as primary stalk cells (Fig. 7 C). Primary stalk cells form the stalk of the antheridium. Primary antheridial cells divide by two successive vertical divisions at right angle to each other to form two tiers of four cells each (Fig. 7 D). A periclinal division is laid down in both the tiers of four cells and there is formation of eight outer sterile jacket initials and eight inner primary androgonial cells (Fig. 7 E).

Jacket initials divide by several anticlinal divisions to form a single layer of sterile antheridial jacket. Primary androgonial cells divide by several

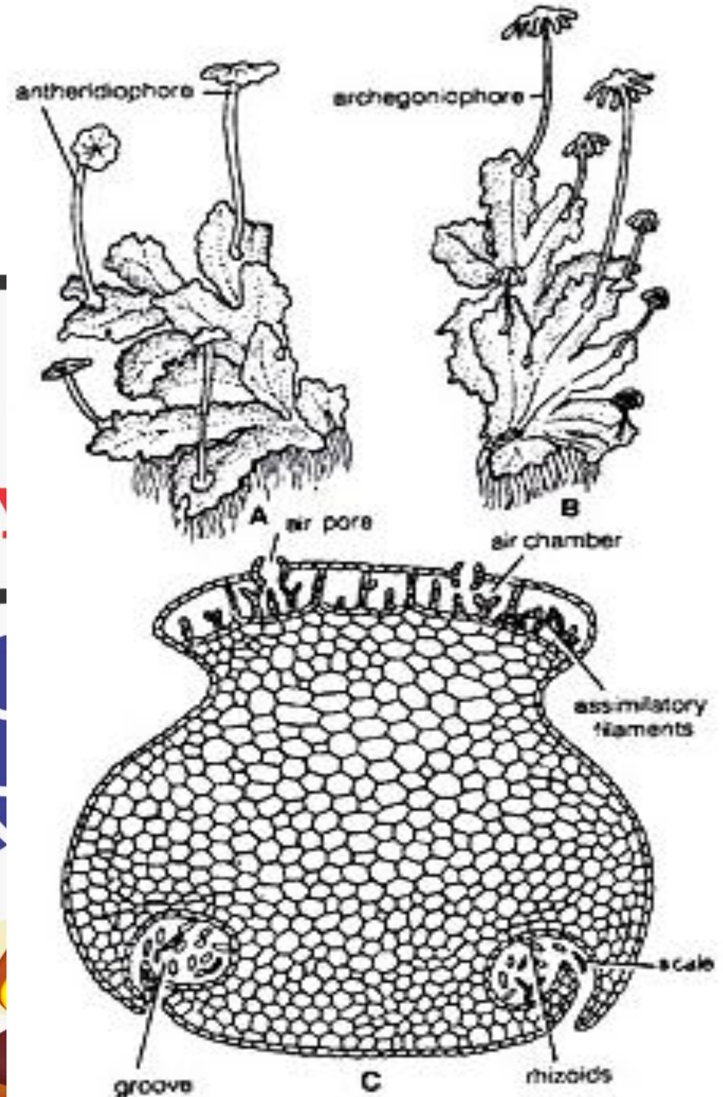


Fig.5. (A-C) *Marchantia:* Gametophores. (A) Thallus bearing antheridiophores (B) Female thallus bearing archegoniophores, (C) Transverse section of gametophore.

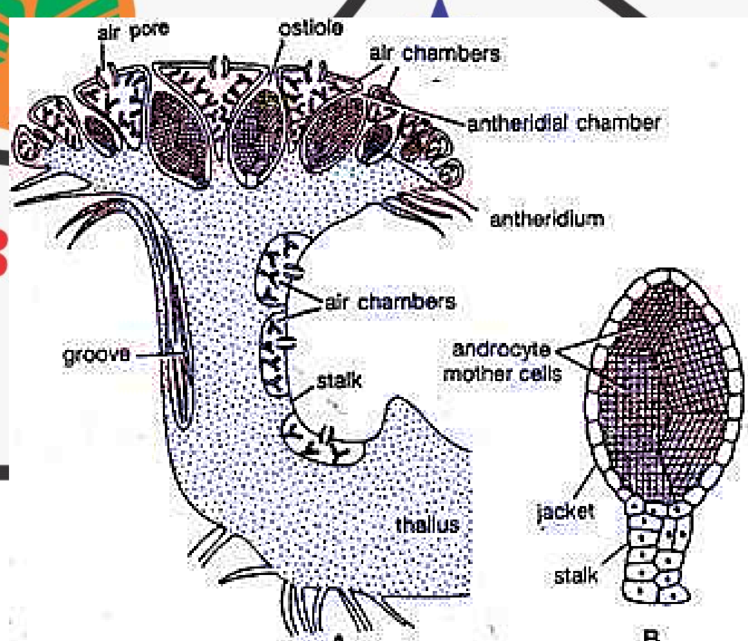


Fig.6. (A-B) *Marchantia:* Antheridia. (A) Vertical or longitudinal section passing through disc of antheridiophore (B) A mature antheridium

repeated transverse and vertical divisions resulting in the formation of large number of small androgonial cells (Fig. 7 F).

The last generation of the androgonial cells is known as androcyte mother cells (Fig. 7 G). Each androcyte mother cells divides by a diagonal mitotic division to form two triangular cells called androcytes. Each androcyte cell metamorphosis into an antherozoid (Fig. 8 A-G).

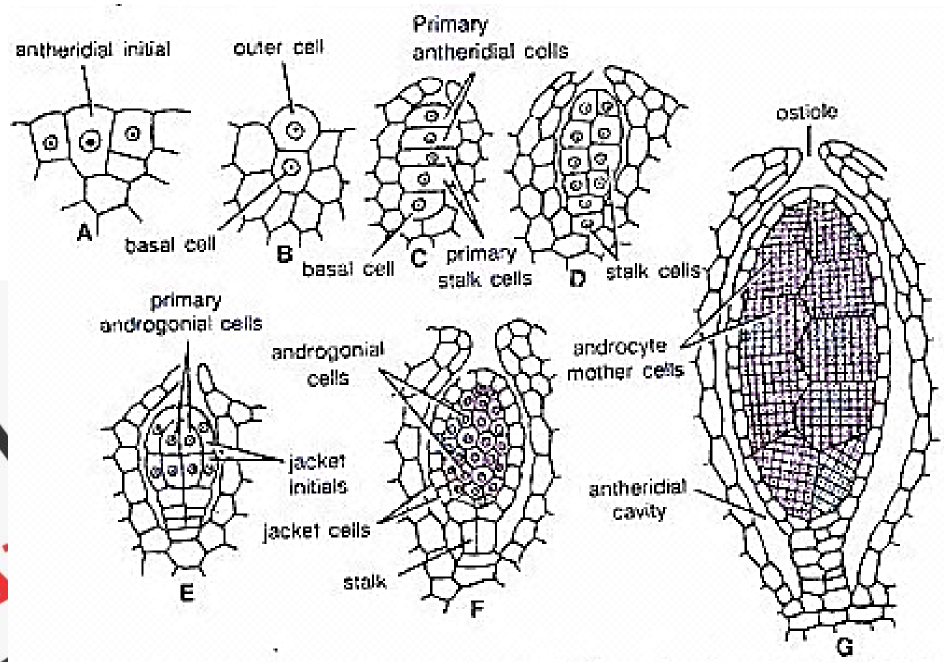


Fig.7. (A-H) *Marchantia:* Development of antheridium (A-F) Successive stages in the development of antheridium (G) A mature antheridium

Spermatogenesis:

The process of metamorphosis of androcyte mother cells into antherozoids is called spermatogenesis.

It is completed in two phases:

(1) Development of blepharoplast. (2) Elongation of androcyte nucleus.

Archegoniophore or Carpocephalum:

It arises at the apical notch and consists of a stalk and terminal disc. It is slightly longer than the antheridiophore. It may be 5-7cm. long. The young apex of the archegoniophore divides by three successive dichotomies to form eight lobed rosette like disc.

Each lobe of the disc contains a growing point. The archegonia begin to develop in each lobe in acropetal succession, i.e., the oldest archegonium near the centre and the young archegonium near the apex of the disc. (Fig. 10 A). Thus, eight groups of archegonia develop on the upper surface of the disc. There are 12-14 archegonia in a single row in each lobe of the disc.

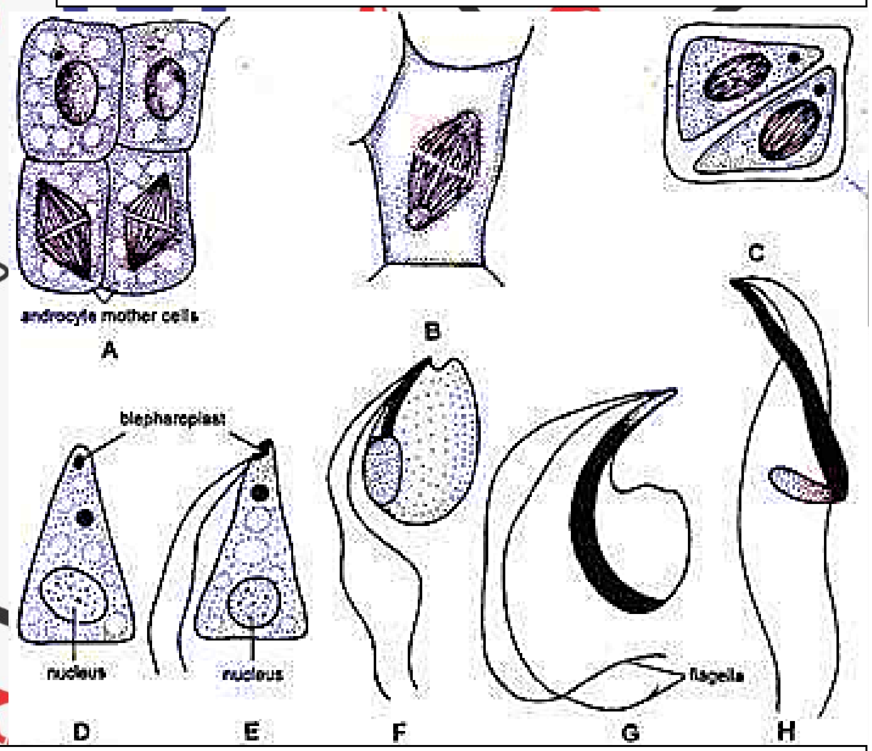


Fig.8. (A-H) *Marchantia:* Spermatogenesis (A-C) Formation of androcytes, (D-G) Stages in spermatogenesis (H) A single antherozoid

Development: (NOT FOR EXAM)

The development of the archegonium starts on the dorsal surface of the young receptacle in acropetal succession. A single superficial cell which acts as archegonial initial enlarges and divides by transverse division to form a basal cell or primary stalk cell and an outer cell or primary archegonial cell (Fig. 9 A, B).

The primary stalk cell undergoes irregular divisions and forms the stalk of the archegonium. The primary archegonial cell divides by three successive intercalary walls or periclinal vertical walls resulting in the formation of three peripheral initials and a fourth median cells, the primary axial cell (Fig. 9 C, D).

Each of the three peripheral initials divide by an anticlinal vertical division forming two cells (Fig. 9 G, H). In this way primary axial cell gets surrounded by six cells. These are called jacket initials (Fig. 9 H, I). Six jacket initials divide transversely into upper neck initials and lower venter initials (Fig. 9 F). Neck initial tier divides by repeated transverse divisions, to form a tube like neck which consists of six vertical rows. (Fig. 9 I). Each row consists 6-9 cells. Venter initials tier also divides transversely to form a single wall layer of swollen venter (Fig 9 K). Simultaneously, the primary axial cell divides transversely and unequally to form upper small primary cover cell and lower large central cell (Fig. 9 E). The central cell divides into primary neck canal cell and a lower venter cell. Primary neck canal cells divides transversely to form a row of about eight thin walled neck canal cells (Fig. 9 J, K). Primary venter cell divides only once and forms a small upper venter canal cell and a lower large egg or ovum (Fig. 9 K). The primary cover cell divide by two vertical divisions at right angle to one another to form four cover cells which form the mouth of the archegonium.

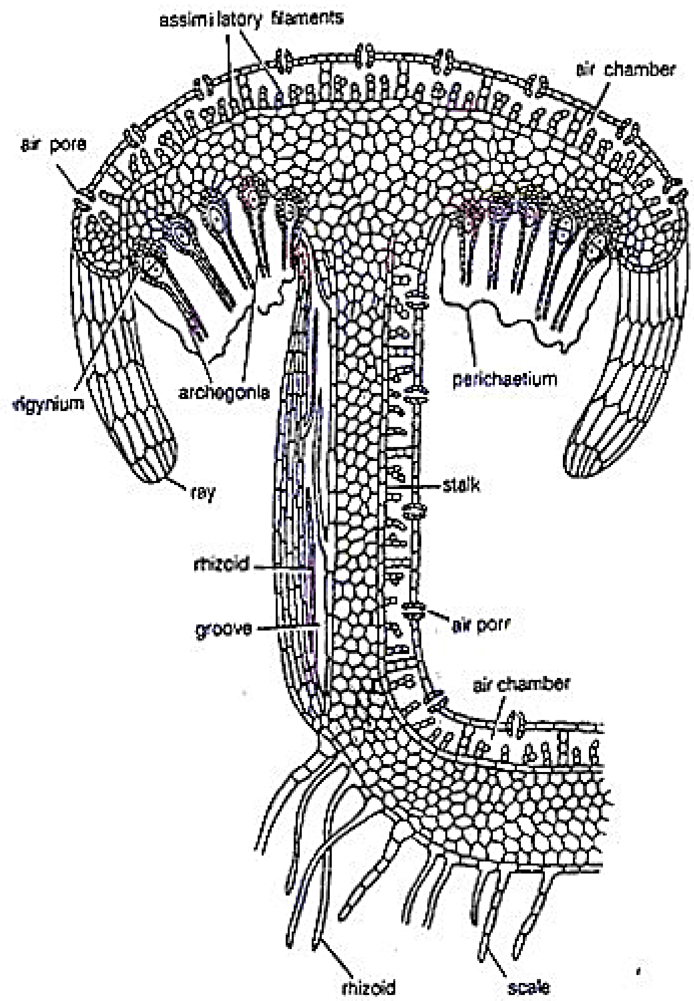


Fig.11. *Marchantia:* Vertical longitudinal section (V.L.S) of archegoniophore showing protective layers and rays. (After fertilization)

Mature Archegonium:

A mature archegonium is a flask shaped structure. It remains attached to the archegonial disc by a short stalk. It consists upper elongated slender neck and basal globular portion called venter. The neck consists of six vertical rows enclosing eight neck canal cells and large egg. Four cover cells are present at the top of the neck. (Fig. 9 L).

Fertilization in *Marchantia*:

Marchantia is dioecious. Fertilization takes place when male and female thalli grow near each other in presence of Water. The neck of the archegonium is directed upwards on the dorsal surface of the disc of the archegoniophore (Fig. 9 A).

In the mature archegonium the venter canal cell and neck canal cells disintegrate and form a mucilaginous mass. It absorbs water, swells up and comes out of the archegonial mouth by pushing the cover cells apart. This mucilaginous mass consists of chemical substances which attracts antherozoids.

The antherozoids are splashed by rain drops. They may fall on the nearby female receptacle or swim the whole way by female receptacle. It is only possible if both the male and female receptacles are surrounded by water.

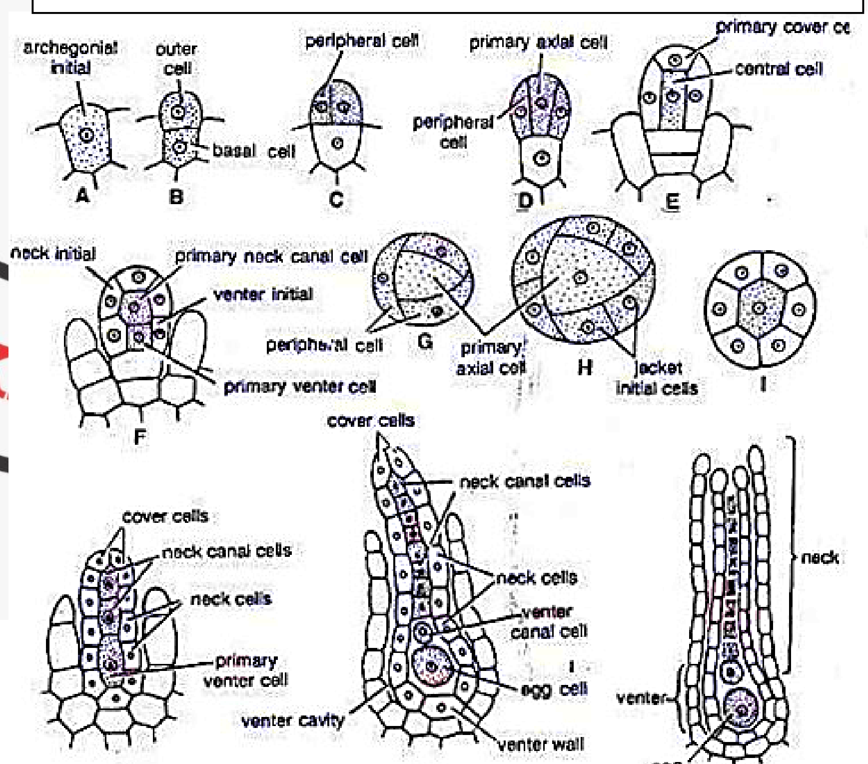


Fig.9. (A-L) *Marchantia:* Development of archegonium (A-K) successive stages in the development of archegonium, (L) A mature archegonium

Many antherozoids enter the archegonial neck by chemotactic response and reach up to egg. This mechanism of fertilization is called splash cup mechanism. One of the antherozoids penetrates the egg and fertilization is effected. The fusion of both male and female nuclei results in the formation of diploid zygote or oospore. Fertilization ends the gametophytic phase.

Sporophytic Phase:

Post Fertilization Changes:

1. Archegoniophore elongates.
2. Remarkable over-growth takes place in the central part of the disc. As a result of this growth the marginal region of the disc bearing archegonia is pushed downward and inward. The archegonia are now hanging towards the lower side with their neck pointing downwards (Fig. 10 B-D).
3. Wall of the venter divides to form 2-3 layered calyptra.
4. A ring of cells at the base of venter divides and re-divides to form a one cell thick collar around archegonium called perigynium (Pseudoperianth).
5. A one celled thick, fringed sheath develops on both sides of the archegonial row. It is called perichaetium or involucre. Thus, the developing sporophyte is surrounded by three protective layers of gametophytic origin i.e., calyptra, perigynium and perichaetium (Fig. 11). The main function of these layers is to provide protection, against drought, to young sporophyte.
6. Between the groups of archegonia, long, cylindrical processes develop from the periphery of disc. These are called rays. They radiate outward, curve downwards and give the disc a stellate form. In *M. polymorpha* these are nine in number.
7. Zygote develops into sporogonium.

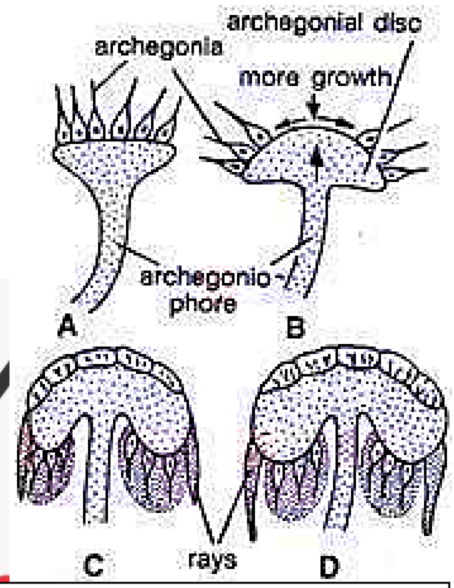


Fig.10. (A-D) *Marchantia:* (A) Position of the archegonia before fertilization, (B-D) Inversion of the archegonia after fertilization

Development of Sporogonium/Sporophyte:
(NOT FOR EXAM)

Diploid zygote or oospore enlarges and it completely occupies the cavity of the archegonium. It first divides by transverse division to form an outer epibasal cell and inner hypo basal cell (Fig. 12 A, B).

The second division is at right angle to the first and results in the formation of four cells (quadrant stage) (Fig. 12 C). The epibasal cell forms the capsule and hypo basal cells form the foot and seta.

Since the capsule is developed from the epibasal cell and forms the apex of the sporogonium, it is known as exoscopic embryogeny. The next division is also vertical and forms eight celled stage or octant stage.

Now the divisions are irregular and globular embryo is formed (Fig. 12 D). The lower cells divide to form a massive and bulbous foot. The cells of the seta divide in one plane to form vertical rows of cells.

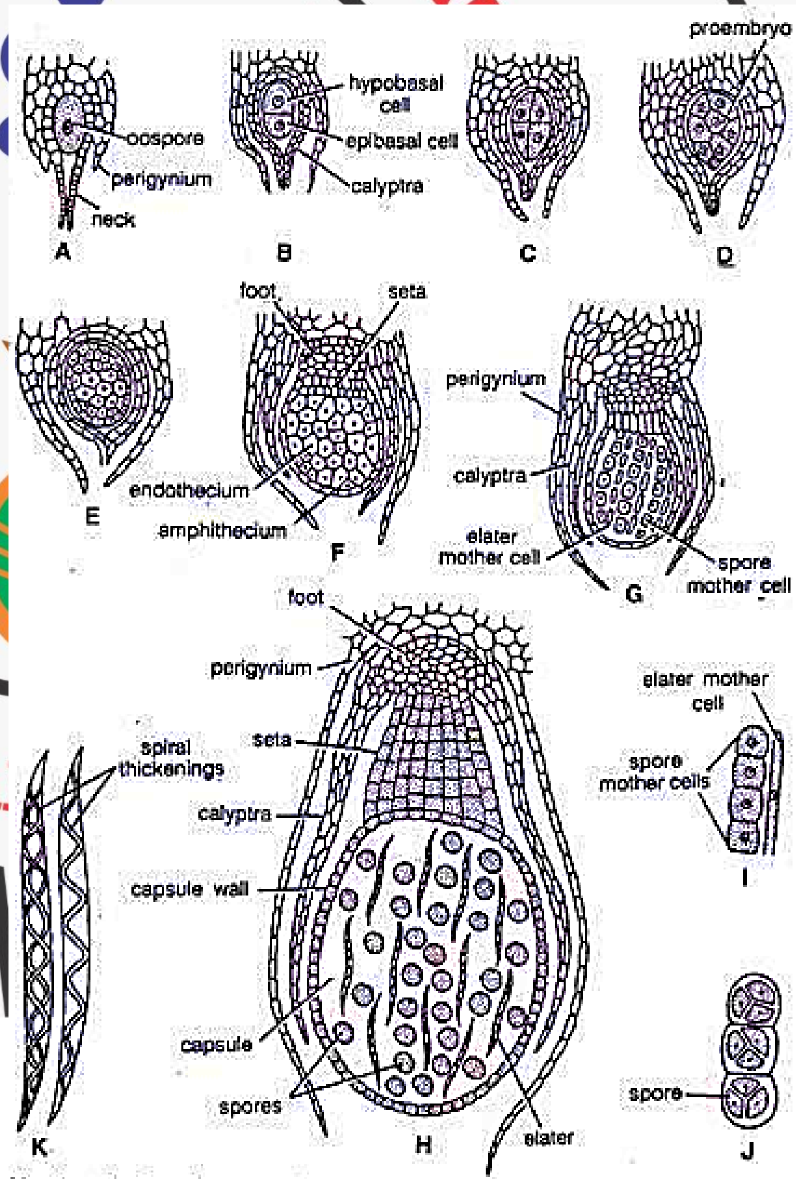


Fig.12. (A-J) *Marchantia:* Development of sporophyte (A-J) successive stages in the development of sporogonium, (H) L.S of A mature sporogonium (J) Spore tetrad (K) Two elaters

In upper region of capsule periclinal division occurs and it differentiates it into outer single layered amphithecium and multilayered endothecium (Fig. 12 E, F).

The cells of the amphithecium divide only by anticlinal divisions to form a single layered sterile jacket or capsule wall. The endothecium forms the archesporium. Its cells divide and re-divide to form a mass of sporogenous cells (sporocytes). Half of the sporogenous cells become narrow and elongate to form the elater mother cells (Fig. 12 G, I) and this elongate considerably to form long, slender diploid cells called elaters. Elaters are pointed at both the ends and have two spiral bands or thickenings on the surface of the wall. These are hygroscopic in nature and help in dispersal of spores (Fig. 12 K). The spore mother cell is diploid and divides meiotically to form four haploid spores which remain arranged tetrahedrally for quite some time (Fig. 12 J). The spores later become free and remain enclosed by the capsule wall along elaters. (Fig. 12 H).

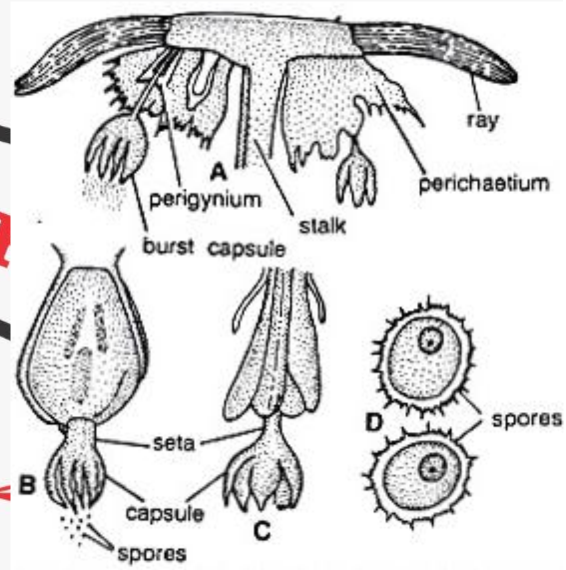


Fig.13. (A-D) *Marchantia:* Dehiscence of capsule (A) V.L.S of archegoniophore after the formation of capsule, (B,C) Dehiscence of capsule (D) Spores.

Mature Sporogonium or Sporophyte:

A mature sporogonium can be differentiated into three parts, viz., the foot, seta and capsule (Fig. 13 H).

Foot: It is bulbous, multicellular- composed of parenchymatous cells. It acts as anchoring and absorbing organ. It absorbs the food from the adjoining gametophytic cells for the developing sporophyte.

Seta:

It connects the foot and the capsule. At maturity, due to many transverse divisions it elongates and pushes the capsule through three protective layers.

Capsule:

It is oval in shape and has a single layered wall which encloses spores and elaters. It has been estimated that as many as 3,00,000 spores may be produced in single sporogonium and there are 128 spores in relation to one elater.

Dispersal of Spores:

As the sporogonium matures, seta elongates rapidly and pushes the capsule in the air through the protective layers (Fig. 13 A). The ripe capsule wall dehisces from apex to middle by four to six irregular teeth or valves. The annular thickening in the cells of the capsule wall causes the valves to roll backward exposing the spores and elaters.

The elaters are hygroscopic in nature. In dry weather they lose water and become twisted. When the atmosphere is wet, they become untwisted and cause the jerking action. Due to this the spore mass loosens and spores are carried out by air currents (Fig. 13 B, C).

Structure of Spore:

Spores are very small (0.012 to 0.30 mm in diameter). They are haploid, uninucleate, globose and surrounded by only two wall layers. The outer wall layer is thick, smooth or reticulate and is known as exospore or exine. The inner wall layer is thin and is called endospore or intine.

Germination of Spores and Development of Gametophyte: (NOT FOR EXAM)

Under favourable conditions, the spores germinate immediately. In first year the spore viability is approximately 100%. Before germination it divides by transverse division to form two unequal cells (Fig. 14 A, B). The lower cell is small in size with relatively poor in cell contents, achlorophyllous and extends to form germ-rhizoid (Fig. 14 C). The large cell

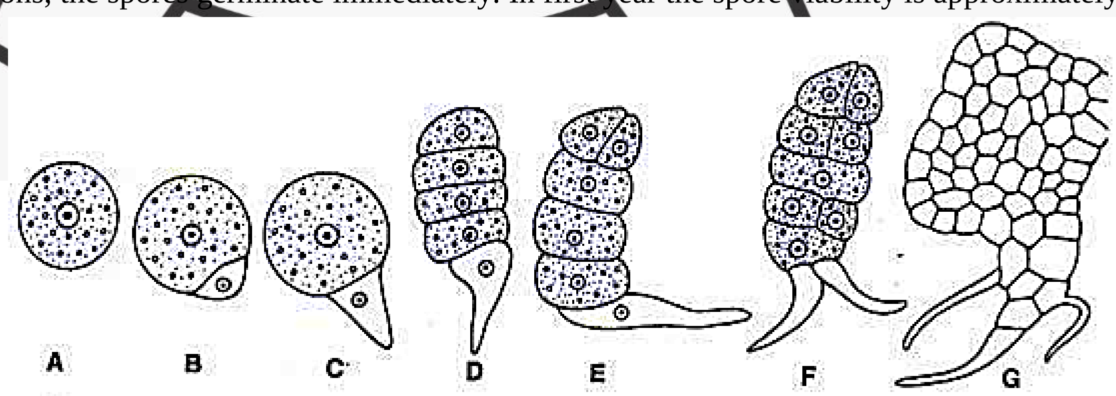


Fig.14. (A-G) *Marchantia:* Successive stages in the germination of spore and development of sporophyte.

is chlorophyllous and undergoes divisions to form a six to eight cell germ-filament or protonema (Fig. 14 D). At this stage the contents of the cells migrate at the apex.

The apex is cut off from the rest of the sporeling by a division. It behaves as apical cell. The apical cell cuts off five to seven cells alternately to the left and right. These cells by repeated divisions form a plate like structure (Fig. 14 F).

By the activity of these marginal cells, the expansion of the plate takes place into thallus, a characteristic of *Marchantia*. *Marchantia* is dioecious, 50% of the spores develop into male thalli and 50% develop into female thalli (Fig. 15).

Alternation of Generation in *Marchantia:*

The life cycle of *Marchantia* shows regular alternation of two morphologically distinct phases. One of the generations is Haplophase and the other is diplophase.

Haplophase or Gametophytic Phase:

In *Marchantia* this phase is dominant and produces the sex organs. Sex organs produce gametes to form a diploid zygote.

Diploid Phase or Sporophytic Phase:

Zygote develops into sporophyte. In Marchantia sporophyte is represented by foot, seta and capsule. The sporophyte produces the spores in the capsule. The spores on germination produce the gametophyte.

So, in *Marchantia* two morphologically distinct phases (Haplophase and Diplophase) constitute the life cycle. The life cycle of this type which is characterised by alternation of generations and sporogenic meiosis is known as heteromorphic and diplohaplontic (Fig. 16).

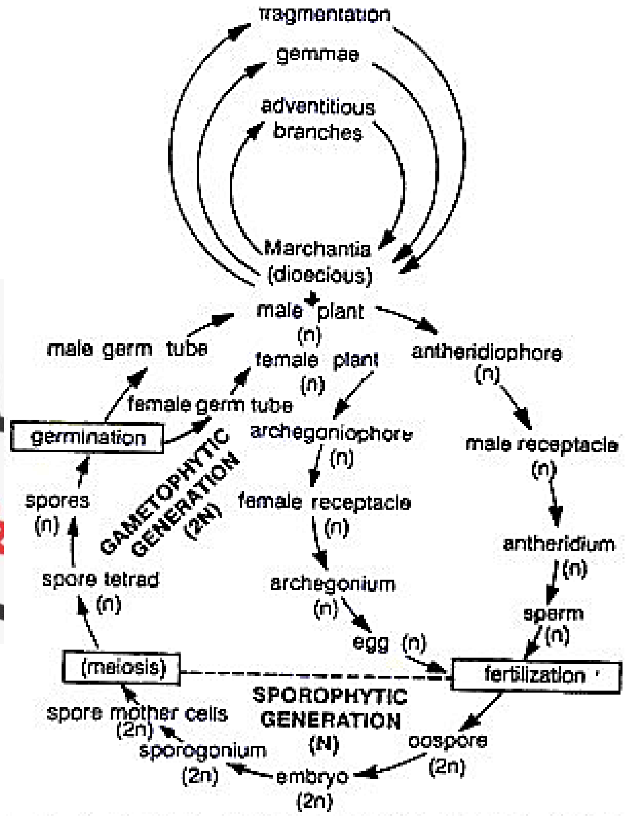


Fig.16. ***Marchantia:*** **Schematic representation of the life cycle.**

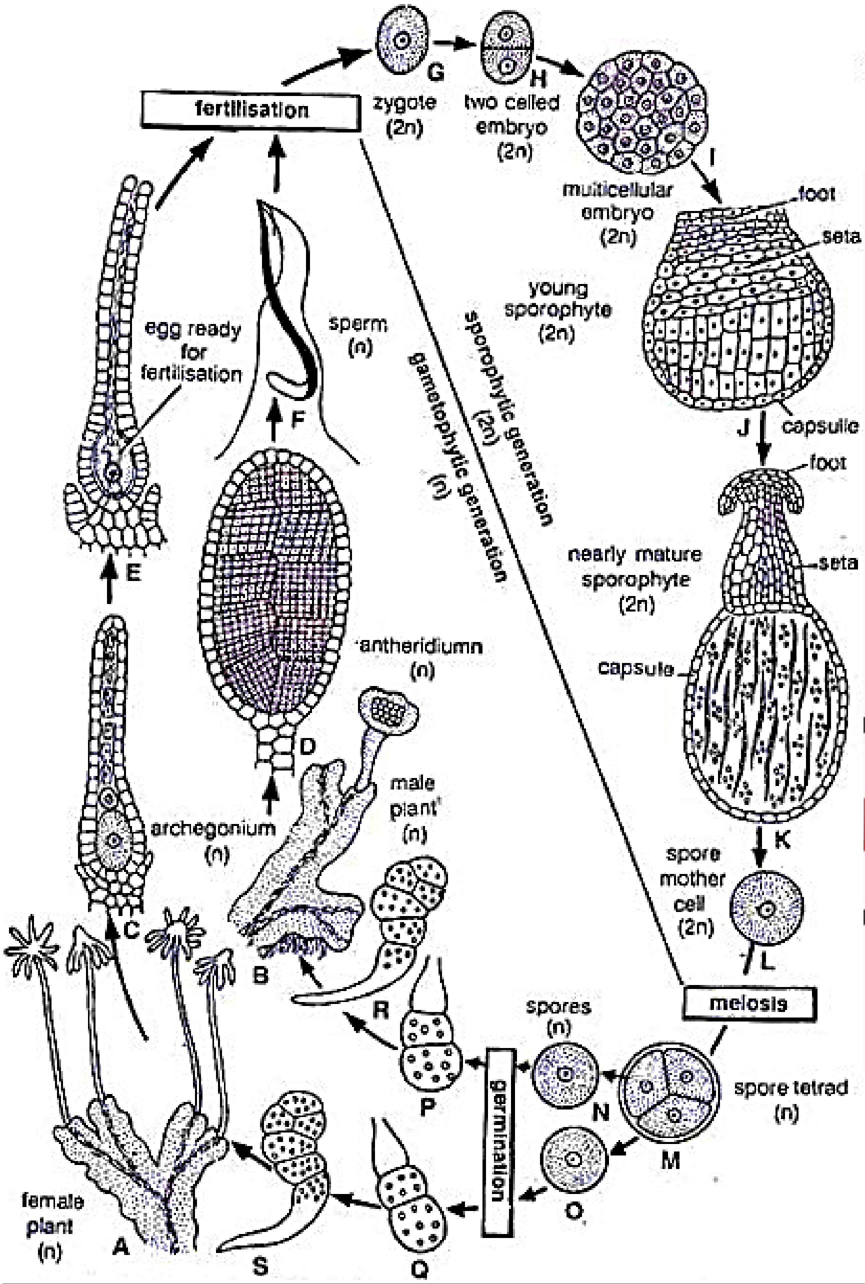


Fig.17. ***Marchantia:*** **Diagrammatic representation of the sexual life cycle.**

Anthoceros

Systematic Position of *Anthoceros*:

Division	:	Bryophyta
Class	:	Anthocerotopsida
Order	:	Anthocerotales
Family	:	Anthocerotaceae
Genus	:	*Anthoceros*

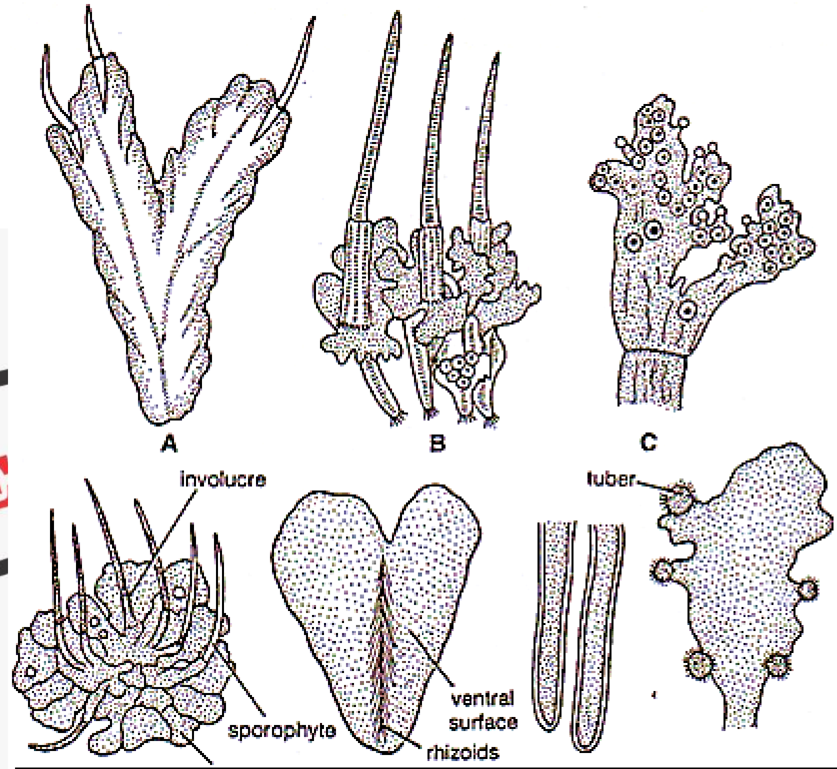


Fig.1. (A-F). *Anthoceros:* External features (A) *A. himalayensis,* (B) *A. erectus,* (C) *A. gemmulosus,* (D) *A. crispulus* (dorsal surface), (E) Ventral surface, (F) Smooth walled rhizoids (G) Thallus with tubers

Distribution and Habitat of *Anthoceros*:

It is represented by about 200 species and are terrestrial with cosmopolitan distribution. They grow in very moist and shady places like slopes, rocks or sides of the ditches. Some species are found growing on decaying wood. *Anthoceros* is usually not well adapted to resist dry conditions.

In India *Anthoceros* is about 25 species. Three species viz., *A. himalayensis*, A. erectus and *A. chambensis* are commonly found growing in the Western Himalayan region. These species are also found growing in Mussoorie, Kulu, Manali, Kumaon, Chamba valley, Punjab, Madras and in plains of South India. Some other species and their distribution are—*A. dixitii*, *A. sahyadrensis* (Poona and neighbouring hills), *A. crispulus* (Lucknow), *A. assamicus* (Assam), *A. shivanandani* (Kerala) etc. The species of *Anthoceros* may be perennial (*A. himalayensis*) or annual (*A. erectus*).

Gametophytic Phase of *Anthoceros*:

External Features:

The gametophytic plant body is thalloid, dorsiventral, prostrate, dark green in colour with a tendency towards dichotomous branching leading to an orbicular or semi orbicular rosette like appearance of the thallus.

The thallus is bilobed (Fig. 1 A) or pinnately branched or spongy with large number of sub-spherical spongy bodies like a gemma (fig. 1 C) or raised on a thick vertical stalk like structure (fig 1. B).

Dorsal Surface:

May be smooth or velvety because of the presence of several lobed lamellae or rough with spines and ridges. It is shining, thick in the middle and without a distinct mid rib (Fig. 1 D).

Ventral Surface:

Bears many unicellular, smooth-walled rhizoids (Fig. 1 E, F) to anchor the thallus on the substratum and to absorb water and mineral nutrients from the soil. Tuberculated rhizoids, scales or mucilaginous hairs are absent. Many small, opaque, rounded, thickened dark bluish green spots can be seen on the ventral surface. These are the mucilage cavities filled with *Nostoc* colonies.

During September and October the mature thalli have erect, elongated and cylindrical sporogonia which are horn like in clusters. Each sporogonium is surrounded by a sheath like structure on its base called involucre (Fig. 1 D).

Internal Structure:

The vertical transverse section (V. T. S.) of the thallus shows a very simple structure. It lacks any zonation (Fig. 2 A, B). It is uniformly composed of thin walled parenchymatous cells. The thickness of the middle region varies in different species. It is 6-8 or 8-10 or 30-40 cells thick. The outer most layer is upper epidermis. The epidermal cells are regularly arranged, smaller in size and have large lens shaped chloroplasts. Each cell of the thallus contains a single large discoid or oval shaped chloroplast. Each chloroplast encloses a single, large, conspicuous body called pyrenoid, a characteristic feature of class Anthocerotopsida (Fig. 2 C, D). 25-300 disc to spindle shaped bodies aggregate to form pyrenoid.

The number of chloroplasts per cell also varies in different species from 1-4. The nucleus lies in the close vicinity of the chloroplast near the pyrenoid (Fig. 2 D).

The air chambers and air pores are absent in *Anthoceros*. However, in a few species intercellular cavities are present on the lower surface of the thallus. These cavities are formed due to break down of the cells (schizogenous).

The cavities are filled with mucilage and are called mucilage cavities. These cavities open on the ventral surface through stoma like slits or pores called slime pores (Fig. 2 B). Each slime pore has two guard cells with thin walls (Fig. 2 F). The guard cells are non-functional and do not control the size of the pore. The pore remains completely open. With the maturity of the thallus the mucilage in the cavities dries out.

It results in the formation of air filled cavities. The blue green algae *Nostoc* invades these air cavities through slime pores and form a colony in these cavities and its beneficial activity is not known. May be symbiotic association. The thallus supplies carbohydrates to the *Nostoc* and the latter, in turn, adds to nitrate nutrients by fixing atmospheric nitrogen. The lowermost cell layer is lower epidermis. Some cells of the lower epidermis extend to form the smooth-walled rhizoids (Fig. 2 B).

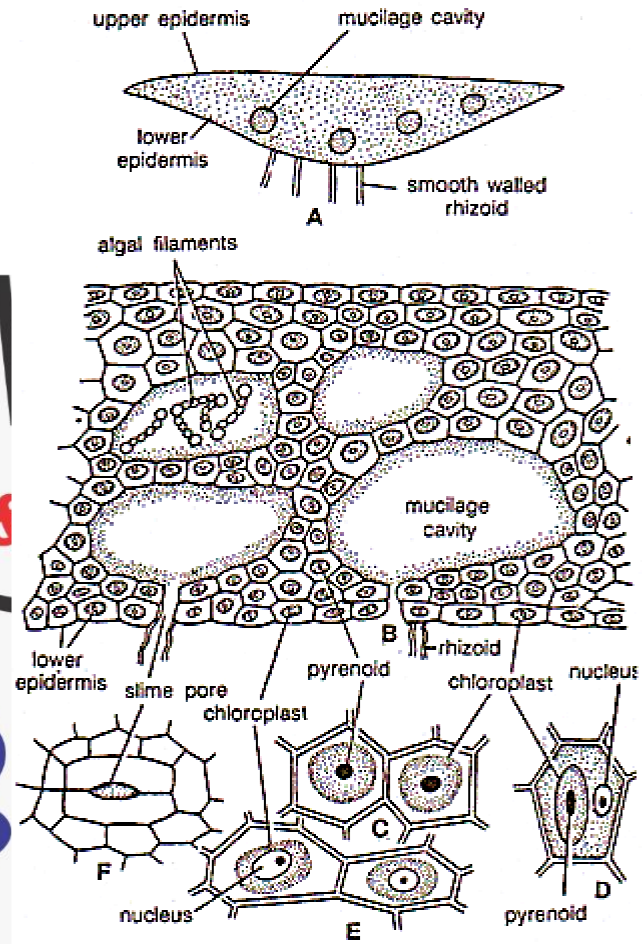


Fig.2. (A-F). *Anthoceros:* Internal structure of the thallus (A) Vertical transverse section of thallus (diagrammatic), (B) V.T.S of thallus (a part cellular), (C) Cells showing chloroplast and pyrenoid,, (D) Cells showing chloroplast, pyrenoid and nucleus, (E) Parenchymatous cells with chloroplast and nucleus, (F) Surface view of slime pore

Reproduction in *Anthoceros*:

It reproduces by vegetative and sexual methods.

Vegetative Reproduction happens by following methods:

1. By death and decay of the older portion of the thallus or fragmentation:

The older portion of the thallus starts rotting or disintegrates due to ageing or drought. As it reaches up to the place of dichotomy, the lobes of the thallus get separated. Thus, detached lobes develop into independent plants by apical growth. This method is not common in *Anthoceros*.

2. By tubers:

Under unfavorable conditions or prolonged drought, the marginal tissues of the thallus get thickened and form the perennating tubers. (Fig. 1 G). Their position varies in different species. They may develop behind the growing points or along the margins of the thallus and may have stalk. The tubers have outer two to three layers of corky hyaline cells which enclose the tissue containing oil globules, starch grains and aleurone granules. They are capable to pass on the unfavorable conditions. On resumption of favourable conditions tubers produce new thalli.

3. By Gemmae:

In some species of *Anthoceros* many multicellular stalked structures develop along the margins of the dorsal surface of the thallus. These structures are called gemmae. When detached from the parent thallus, each gemma develops into new plant.

4. By persistent growing apices:

Due to prolonged dry summer or towards the end of the growing season, the whole thallus in some species of *Anthoceros* dries and gets destroyed except the growing point. Later it grows deep into the soil and becomes thick under unfavorable conditions. It develops into new thallus. It is more a method of perennation then multiplication.

5. By apospory:

In *Anthoceros*, unspecialized cells of the many parts of the sporogonium (for e.g., intercalary meristematic zone, sub epidermal and sporogenous region of the capsule) form the gametophytic thallus. This phenomenon is called apospory. The thalli are diploid but normal in appearance.

Sexual reproduction:

Sexual reproduction is oogamous. Male reproductive bodies are known as antheridia and female as archegonia. Some species of *Anthoceros* are monoecious while some species like are dioecious. The monoecious species are protandrous i.e., antheridia mature before archegonia.

Antheridium:

Structure:

A mature antheridium has a stalk and club or pouch like body. The stalk attaches the antheridium to the base of the antheridial chamber. Stalk may be slender and composed of four rows of cells (Fig. 3 I) or more massive (Fig. 3 J). A single or a group of two to four or more antheridia are present in the same antheridial chamber (Fig. 3 H). A single layered sterile jacket encloses the mass of androcytes which metamorphosis into antherozoids.

The Antherozoid:

A mature antherozoid is unicellular, uninucleate, bi-flagellated and has a linear body. The flagella are of almost the same length as the body (Fig. 3 K, L).

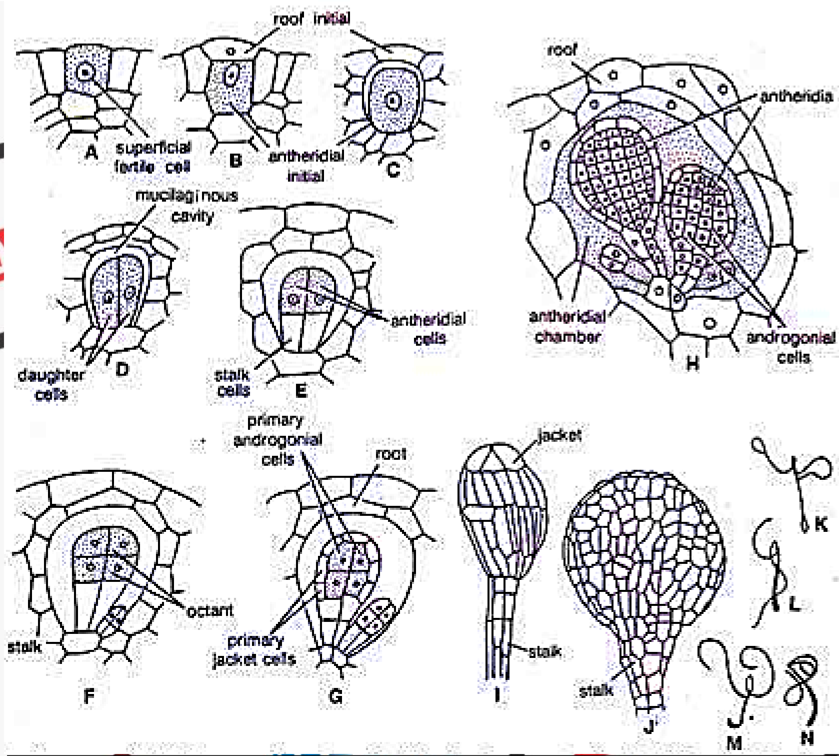


Fig.3. (A-N). ***Anthoceros:*** **(A-H) Successive stages in the development of antheridium (I-J) A mature antheridium (K-N) Antherozoids**

Development: (NOT FOR EXAM)

The development of the antheridium starts from a superficial dorsal cell. It divides by periclinal division into an outer roof initial and inner antheridial initial (Fig. 3 A, B). The antheridium develops from the inner cell. Hence, the antheridium is endogenous in origin. Soon after the division a mucilaginous filled space develop between the antheridial initial and roof initial. (Fig. 3 C).

The roof initial divides by periclinal divisions followed by many anticlinal divisions to form two layered roof of the antheridial chamber. The antheridial initial either directly develops into a single antheridium or it may divide vertically into two, four or sometimes more daughter cells.

Each of the daughter cells functions as antheridial initial. The antheridial initial divides by two vertical divisions at right angle to each other to form four cells (Fig. 3 D). All the four cells divide by transverse division to form eight cells, arranged in two tiers of four cells each (Fig. 3 E). The cells of the lower tier are called stalk cells. These cells divide and re-divide by transverse divisions to form multicellular stalk of the antheridium.

The four cells of the upper tier form the body of the antheridium. These cells divide by transverse division to form eight cells (Fig. 3 F).

Each cell of the octant divides by a curved periclinal division to form the eight outer primary jacket cells and eight inner primary androgonial cells (Fig. 3 G). Primary androgonial cells divide by several repeated transverse and vertical division resulting in the formation of large number of small cubical androgonial cells.

The last generation of androgonial cells is known as androcyte mother cells. Each androcyte mother cell divides by a diagonal mitotic division to form the two triangular cells called androcytes. The protoplast of each androcyte metamorphosis into bi-flagellated antherozoid. (Fig. 3 H).

Dehiscence of Antheridium: Water helps in the dehiscence of the antheridium. As the antheridia mature the roof of the antheridial chamber breaks down irregular, exposing the antheridia in a cup like chamber. The antheridia absorb water and the uppermost tier of triangular cells fall apart releasing a mass of antherozoids.

After dehiscence the antheridium loses turgor and collapses. It is followed by another antheridia to converge towards the opening in the roof and in this way a continuous stream of antherozoids is possible. It explains the formation of large number of sporophytes in Hornworts. (fig 4).

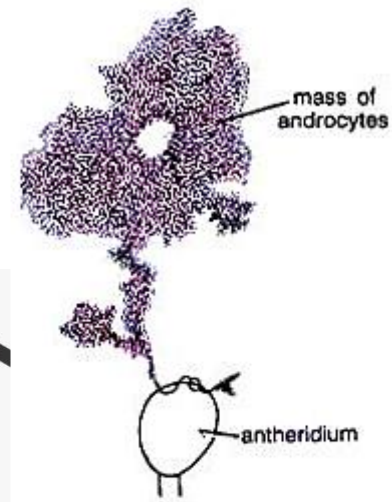


Fig.4. ***Anthoceros:*** **Dehiscence of antheridium**

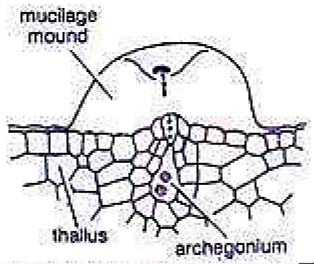


Fig.5. ***Anthoceros:*** **Mature archegonium with mucilage mound**

Archegonium: Archegonia develop in the flesh of the thallus on dorsal surface. The place of an archegonium on a thallus can be identified by the presence of a mucilage mound (Fig. 5).

Structure:

A mature archegonium consists of two to four cover cells, an axial row of four to six neck canal cells, a venter canal cell and an egg. The jacket layer is not distinct from the other vegetative cells (Fig. 6 G, H).

Development: (NOT FOR EXAM)

The development of the archegonium starts on the dorsal surface of the thallus from a single superficial cell which acts as an archegonial initial (Fig. 6 A). It can be differentiated from other cells by its dense protoplasm.

The archegonial initial may divide by transverse division to form an upper primary archegonial cell and lower primary stalk cell or it may directly functions as primary archegonial cell.

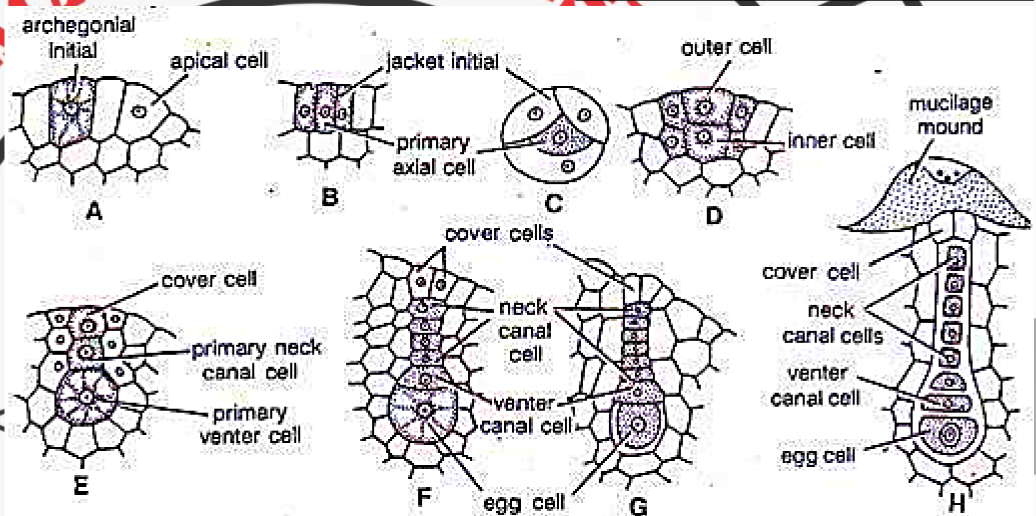


Fig.6 (A-H). ***Anthoceros:*** **Development of archegonium. (A-H) Successive stages in the development of archegonium.**

The primary archegonial cell divides by three successive intersecting walls or periclinal vertical walls to form the three peripheral initials or jacket initials and a fourth median cell, the primary axial cell (Fig. 6 B, C). Jacket initials divide by transverse divisions to form into two tiers of three cells each. The cells of the upper tier divide by anticlinal division to form six cells.

These cells divide transversely to form a jacket of six rows of sterile neck cells. The three cells of the lower tier divide by transverse and vertical divisions to form venter wall. Since the archegonium is embedded in the thallus, it is difficult to trace the development of the cells and to distinguish them from the vegetative cells (Fig. 6).

The primary axial cells divide by a transverse division to form an outer cell and inner (central) cell (Fig. 6 D). The outer cell divides by a transverse division to form terminal cover initial and inner primary neck canal cell (Fig. 6 E). The inner cell directly functions as primary venter cell and divide only once to form upper small venter canal cell and a lower large egg. Primary neck canal cell divides by series of transverse divisions to form four to six neck canal cells. Cover initial divided by one to two vertical division to form two to four rosette like cover cell at the tip of the neck (fig 6 G, H).

Fertilization:

Water is essential for fertilization. In the mature archegonium, the venter canal cell, neck canal cells disintegrate and form a mucilaginous mass. It absorbs water, swells up and becomes out of the archegonial neck by pushing the cover cells apart. This mucilaginous mass becomes continuous with the mucilage mound and in this way an open passage down to egg is formed.

The mucilaginous mass consists of chemical substances. Many antherozoids caught in the mucilage enter in the archegonial neck because of the chemotactic response, reach upto the egg, and fertilization is effected. Prior to fertilization, egg enlarges and fills the cavity of the venter. Fusion of both male and female nuclei results in the formation of diploid zygote or oospore. Fertilization ends the gametophytic phase.

Sporophytic Phase:

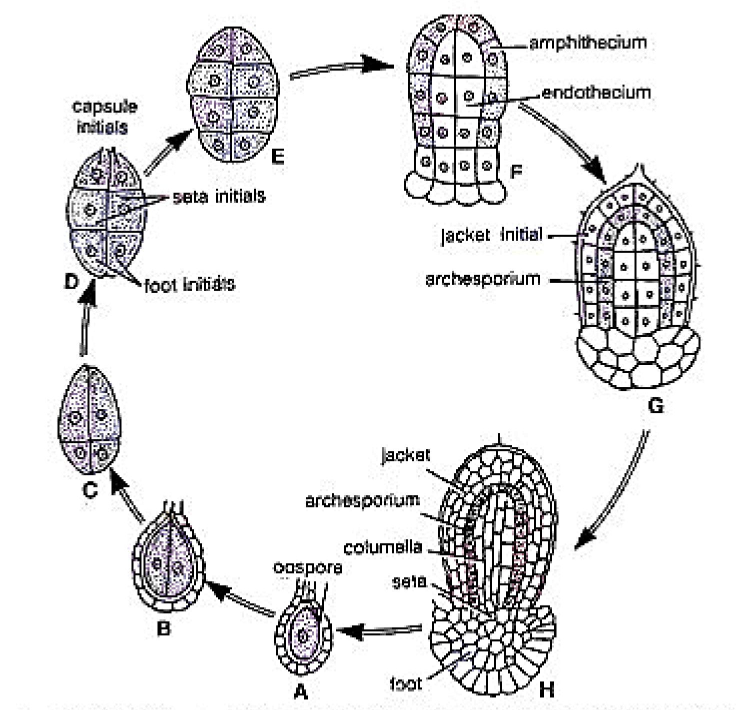


Fig. 7. (A-H). *Anthoceros*. Successive stages in the development of sporophyte.

After fertilization the diploid zygote or oospore still enlarges in size and fills the cavity of the venter of the archegonium. It secretes an outer cellulose wall.

Development of Sporophyte: (NOT FOR EXAM)

The first division of the zygote (Fig. 7 A, B) is vertical. In other Bryophytes the first division of the zygote is transverse. This is the important difference in the development of sporophyte of Hornworts and rest of the Bryophytes.

The second division is transverse (Fig. 7 C) and is so oriented that the upper two cells are usually longer than the lower two (quadrant stage). All the four cells divide by vertical walls to produce eight cells (octant stage). The eight cells are arranged in two tiers of four cells each.

Further development of the sporophyte varies in different species. In majority of the species upper tier of four cells divide by transverse division to form three tiers of four cells each (Fig. 7 D). The lowermost tier forms the foot, the middle tier forms the meristematic zone or intermediate zone and uppermost tier develops into the capsule.

The four cells of the lower tier divide by irregular divisions to form broad, bulbous foot, made up of parenchymatous cells.

The uppermost tier of four cells which forms the capsule divide by one to two transverse divisions to form two to three tiers of cells.

It is followed by periclinal division to form an outer layer of amphithecium and the central mass of cells called endothecium (Fig. 7 F). The entire endothecium develops into the sterile columella. The amphithecium divides by a periclinal division to differentiate into an outer sterile layer of jacket initials and inner fertile layer (Fig. 7 A).

The cells of the jacket initials divide by anticlinal and periclinal divisions to form four to six layered capsule wall. The outermost layer of the capsule wall is called epidermis (Fig. 8 A). In young sporophyte the archesporium over arches the columella (Fig. 7 G). The archesporium may be single layered in thickness throughout or become two layered or two to four layered.

On maturity the archesporium gives rise to two types of cells: spore mother cells and elater mother cells. These cells are arranged in alternate manner one above the another (Fig. 8 A).

Spore mother cells are spherical or oval with dense cytoplasm and large nuclei. These cells divide by meiotic divisions to form spore tetrads (Fig. 8 A). Elater mother cells are elliptical with small nuclei. These cells divide mitotically to form four celled elaters.

The four cells of the elaters may remain attached to each other or may break into 1-celled, 2-celled or 3-celled units. The broken units are called pseudo elaters. (The elaters are without thickening bands and therefore, called pseudo elaters, Fig. 8 A). By the activity of the meristematic zone various tissues of the capsule are continuously produced so that it becomes elongated.

The young sporophyte of the *Anthoceros* is surrounded by a fleshy covering or sheath. It is called involucre (Fig. 8 A). It is developed partly from the tissue of the archegonium and partly from the tissue of the gametophytic thallus.

Structure of Mature Sporogonium:

The mature sporophyte consist a bulbous foot and a smooth, slender, erect, cylindrical, structure called capsule. Capsule varies in length from two to fifteen centimeter in different species. The sporogonium appears like a **'bristle'** or **'horn'**, hence, the species are called 'hornworts' (Fig. 1 A, 8 A).

Internal structure:

A mature sporogonium can be differentiated into three parts viz., the foot: seta and the capsule.

Foot:

It is bulbous, multicellular and made up of a mass of parenchymatous cells. It acts as haustorium and absorbs food and water from the adjoining gametophytic cells for the developing sporophyte (Fig. 8 A).

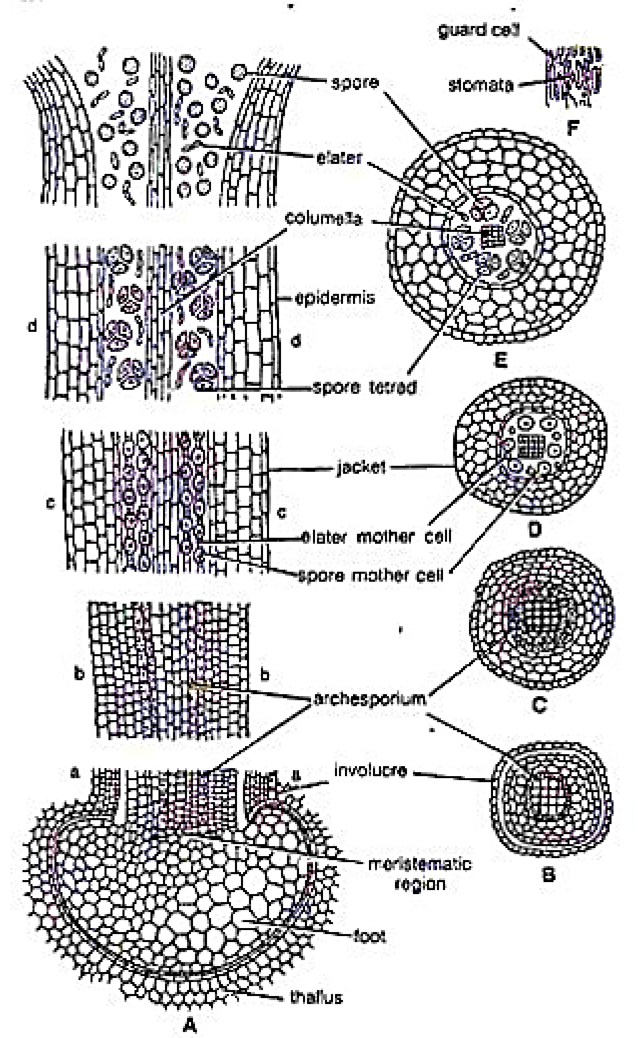


Fig. 8. (A-F). *Anthoceros.* **Internal structure of the sporogonium (A) Longitudinal Section (L.S.) through the mature sporogonium. (B) Cross section of the sporogonium at a–a level, (C) cross section of the sporogonium at b–b level, (D) cross section of the sporogonium at c–c level, (E) Cross section of the sporogonium at d–d level, (F) Structure of stomata from the epidermis of sporogonium wall.**

Meristematic Zone or Intermediate Zone or Intercalary Zone:

Seta is represented by meristematic zone. This is present at the base of the capsule and consists meristematic cells. These cells constantly add new cells to the capsule at its base.

The presence of meristem at the base enables the capsule to grow for a long period and form spores. It is a unique feature of *Anthoceros* and is not found in any other bryophyte. We are able to see different stages of development from base upwards in the sporogonium of *Anthoceros* (Fig. 8 A).

Capsule:

Its internal structure can be differentiated into following parts:

Columella:

It is central sterile pan, extending nearly to its tip. In young sporophyte it consists of four vertical rows of cells but in mature sporophyte it is made up of 16 vertical rows of cells (4 x 4). In a transverse section these cells appear as a solid square (Fig. 8 D, E). It provides mechanical support, functions as water conducting tissue and also helps in dispersal of spores.

Archesporium:

It is present between the capsule wall and the columella. It extends from base to the top of the capsule. It originates from the inner layer of amphithecium. In young sporophyte it over arches the columella (a feature in contrast to liverworts).

In a few species, the archesporium may remain one cell in thickness throughout its further development or it may become two layered thick a little above the base or it may even become two to four cells in thickness (Fig. 8 A, a-a).

In upper part of the capsule it is differentiated into sporogenous tissue which produces spores and pseudo elaters. Pseudo elaters may be unicellular or multicellular, branched or un-branched and may consists more or less elongated cells (Fig. 9 A-D).

Capsule wall:

It consists of four to six layers of cells, of which the outermost layer is epidermis (Fig. 8 A, d-d). The cells of the epidermis are vertically elongated and have deposit of cutin on their walls. The continuity of epidermis is broken by the presence of stomata. Each stoma consists a pore surrounded by two guard cells (Fig. 8 F). The cells of the inner layers have intercellular spaces and contain chloroplast. Thus, the sporogonium is partially self-sufficient to synthesize its own organic food but partially it depends on the gametophyte for the supply of water and mineral nutrients.

Dehiscence of the capsule: (NOT FOR EXAM)

Capsule dehisces basipetally i.e., from apex to base. As the capsule matures, its tip becomes brownish or black. Vertical lines of dehiscence appear in the jacket layer (Fig. 9 E). The dehiscence of the capsule is usually by two longitudinal lines, occasionally it is by single line (Fig. 9 F) or rarely by four lines. The capsule wall dries and shrinks at maturity.

Consequently narrow slits appear in the capsule wall all along the shallow grooves (line of dehiscence), which gradually widen and extend, towards the base. It results in the formation of two valves of the capsule wall (Fig. 9 G). Still attached at the tip and exposing the columella is the mass of spores and pseudo elaters. The two valves thus separated, diverge and twist hygroscopically. The pseudo elaters also dry out, twist and help to loosen the spores. Thus, the twisting of the valves and the movement of the pseudo elaters in the exposed spore mass helps in the shedding of the spores. Air currents also help in the dispersal of spores.

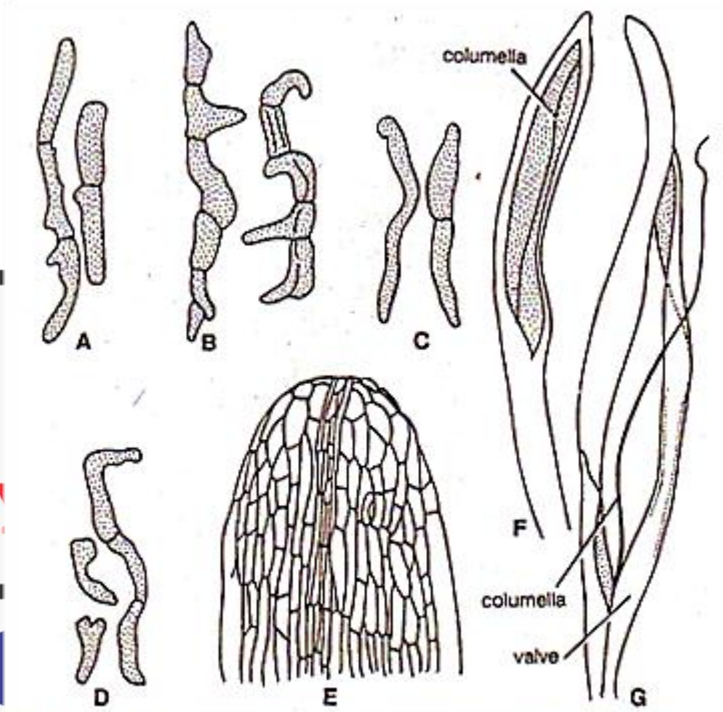


Fig. 9. (A–G). *Anthoceros* (A–D). Pseudoelaters of different species, (E). Apex of the capsule with line of dehiscence, (F) Single line of dehiscence, (G) Bivalved dehiscence.

Structure of Spore:

The spores are haploid, uninucleate, semicircular with a conspicuous triradiate mark (Fig. 10 A).

Each spore has two wall layers. The outermost layer is thick ornamented and is known as exospore. It varies in colour from dark brown to black or yellowish. The inner layer is thin and is known as endospore.

Germination of spore and formation of young gametophyte: (NOT FOR EXAM)

Under favourable conditions the spores germinate immediately or undergo a resting period of few weeks or months before germination. At the time of germination spore absorbs water and swells up. Exospore ruptures at the triradiate mark and endospore comes out in the form of a germ tube (Fig. 10 B).

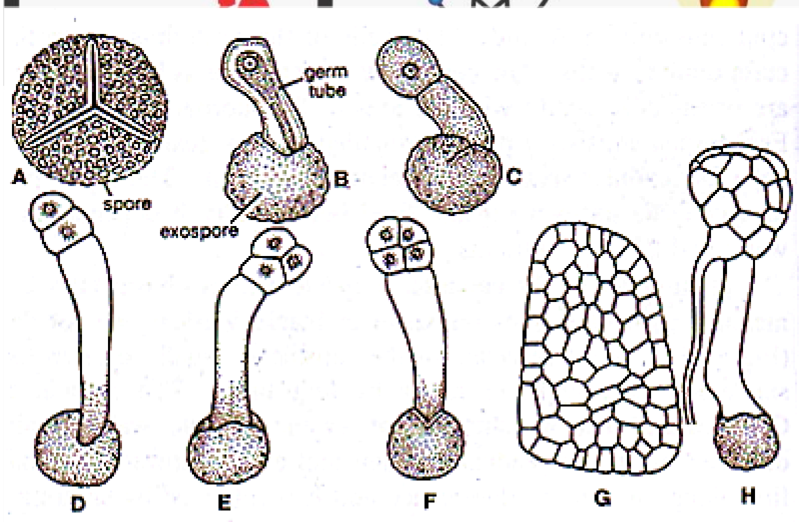


Fig. 10. (A–H). *Anthoceros*. Successive stages in the germination of spore and formation of gametophyte.

Contents migrate into the germinal tube where the colourless plastids turn green. Two successive transverse division at the tip of the germinal tube resulting in the formation of three celled filament (Fig. 10 C, D). The upper cell divides by a vertical division (Fig. 10 E) followed by similar vertical division in the lower cell (quadrant stage Fig. 10 F).

These four cells again divide by a vertical division at right angle to first to form eight cells (octant stage). This octant stage is known as sporeling. The upper tier of four cells function as apical cells and form the new gametophyte. First rhizoid develops as an elongation of any cell of the young thallus (Fig- 10 G, H). As the growth proceeds, the mucilage slits appear on the lower surface and these slits are infected by *Nostoc*.

Alternation of Generation:

The life cycle of *Anthoceros* show regular alternation of two morphologically distinct phases. One of these generations is haplophase and the other is diplophase.

Haplophase or gametophytic phase:

In *Anthoceros* this phase is dominant and produces the sex organs. Sex organs produce gametes to form a diploid zygote.

Diploid phase of sporophytic phase:

Zygote develops into sporophyte. In *Anthoceros* sporophyte is represented by foot, meristematic zone and capsule. The sporophyte produces the spores in the capsule. The spores on germination produce the gametophyte.

So, in *Anthoceros*, two morphologically distinct phases (haplophase and diplophase) constitute the life cycle. The life cycle of this type which is characterised by alternation of generation and sporogenic meiosis is known as heteromorphic and diplohaplontic. (Fig. 11,12).

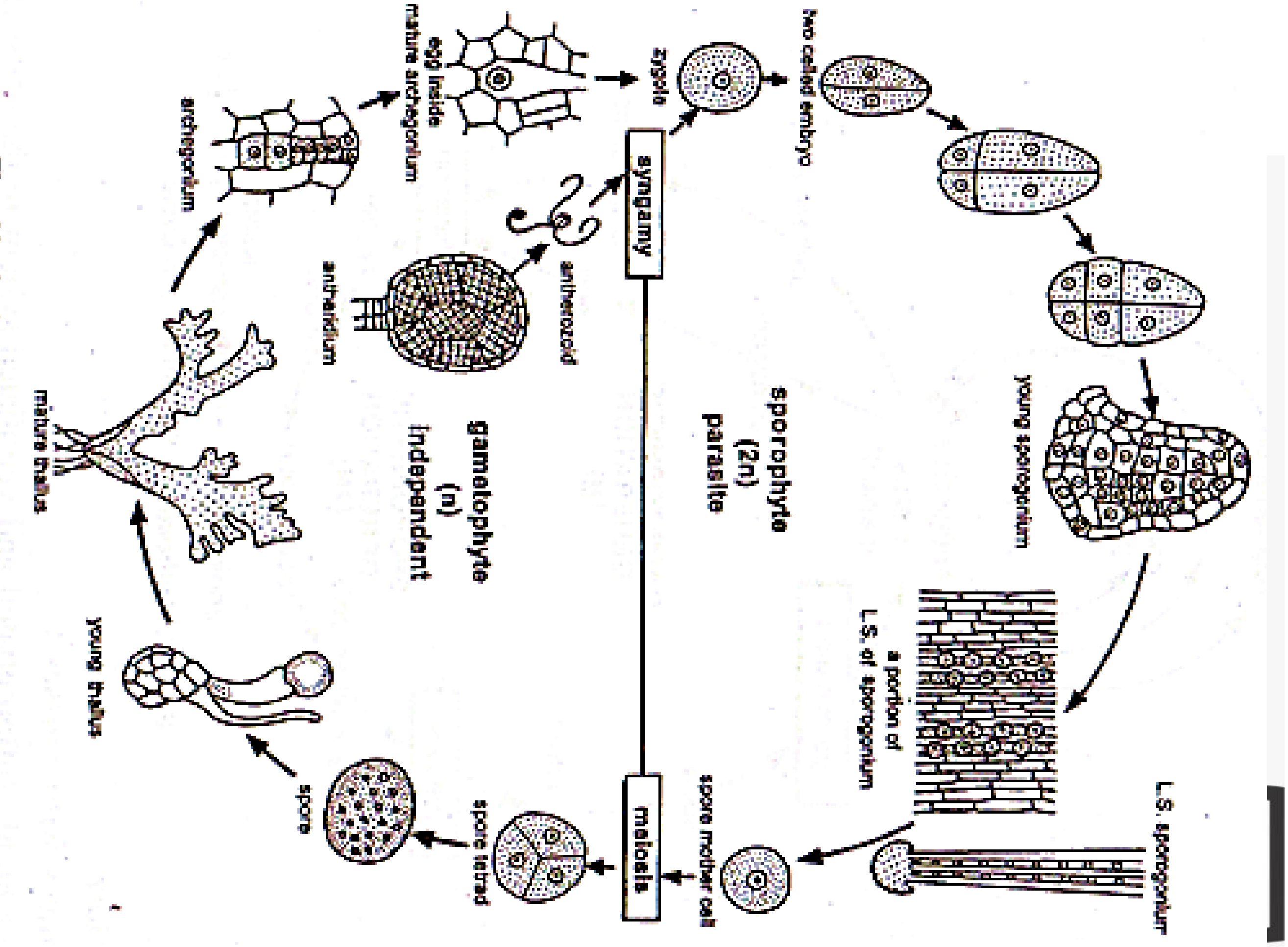


Fig. 11. *Anthoceros*. Diagrammatic life cycle.

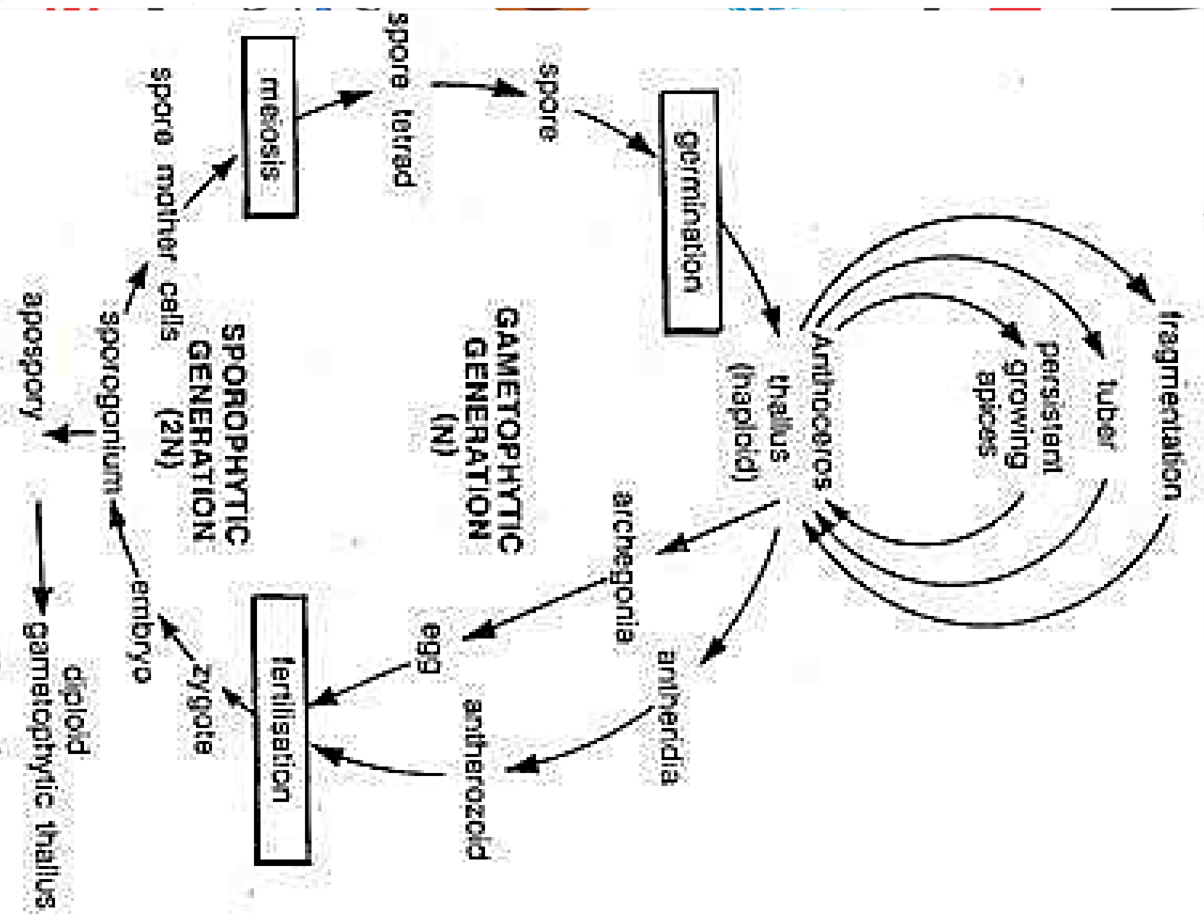


Fig. 12. *Anthoceros*. Schematic life cycle.

Funaria

Systematic Position of *Funaria*

Kingdom : Plantae
Division : Bryophyta
Class : Bryopsida
Order : Funariales
Family : Funariaceae
Genus : *Funaria*
Species : *hygrometrica*

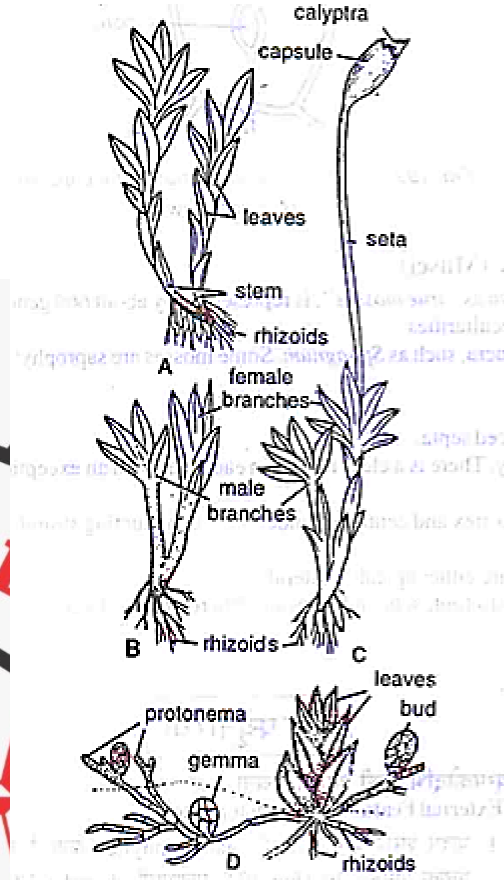


Fig. 194. Funaria. A, Vegetative plants; B, Plants with male and female branches; C, A mature plant bearing a sporophyte; D, Protonema and young gametophyte.

Habitat:

The genus *Funaria* includes about 117 species which are cosmopolitan in nature. They are the common moss, also known as cord moss or green moss. It forms velvety tufts on moist ground, rocks, tree trunks, under shade, banks, burnt grounds etc. About 18 species of *Funaria* have been reported from India. *Funaria hygrometrica* is a common moss on Indian hills.

Habit:

External Features of *Funaria*:

Vegetative structure of gametophyte

Its plant body is composed of protonema and gametophore.

a) Protonema: Protonema is a prostrate, green, branched filamentous structure. It gives rise to erect leafy shoots called gametophores. Protonema is short-lived.

b) Gametophore: The adult plant consists of **gametophores** only. Each gametophores is differentiated into stem, leaves and rhizoids. Actually eight leaves are arranged in three complete spirals forming 3/8 phyllotaxy corresponding to the three cutting faces when young. The leaves are simple, sessile, ovate, with pointed apex, smoothed margin, attached to the stem by a broad base (Fig. &.47B). The mature leaves have midribs but younger leaves are devoid of midribs. In a mature gametophore, the lower few colourless, small, membranous, scale-like leaves are found on prostrate branches and on lower portion of erect branches and are called scaly leaves; middle bigger, green leaves are called foliage leaves; and uppermost compactly arranged leaves forming a rosette are called perichaetial leaves. They bear sex organs at their apices. Rhizoids arise from the base of each gametophores. The rhizoids are strong, much-branched multicellular (Fig. 6.48B). They are characterized by the presence of oblique septa. Young rhizoids are colourless but become brown or black when mature. They function as anchoring and "absorbing organs.

(ii) Internal Structure:

1. Axis or **'stem'**

The transverse section (T. S.) of axis can be differentiated into three distinct regions:

(i) Epidermis
(ii) Cortex
(iii) Central conducting strand or central cylinder.

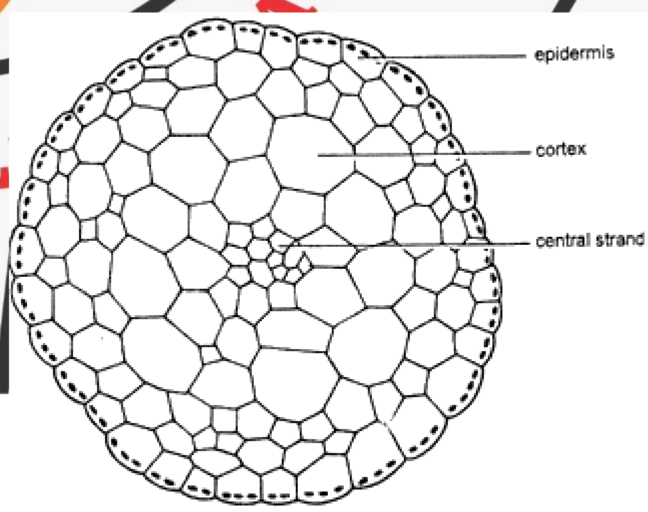


Fig. 2. *Funaria*. Transverse section (T.S.) of axis.

(i) Epidermis:

It is the outer most single layered protective covering consisting of small tangentially elongated chlorophyll bearing cells. Cuticle and stomata are absent (Fig. 2).

(ii) Cortex:

It is present between the epidermis and conducting tissue. It is made up to parenchymatous cells. Younger part of the cortex contains chloroplasts but in the older part they are lacking. At maturity few outer layers of cortex become thick walled and are reddish brown in colour but those of the inner layers become thin walled.

(iii) Central Conducting Strand:

It is made up of long, narrow thin walled dead cells which lack protoplasm. These cells are now commonly called as hydroids. Conducting strand besides providing a certain amount of mechanical support, functions in the upward conduction of water and solutes.

2. Leaf:

Transverse section (T. S.) of **'leaf'** shows a well-defined midrib with two lateral wings. Except the midrib region, the **'leaf'** is composed of single layer of parenchymatous polygonal cells. The cells contain many large and prominent chloroplasts (Fig. 3). The central part of the mid rib has narrow conducting strand of thick walled cells which help in conduction.

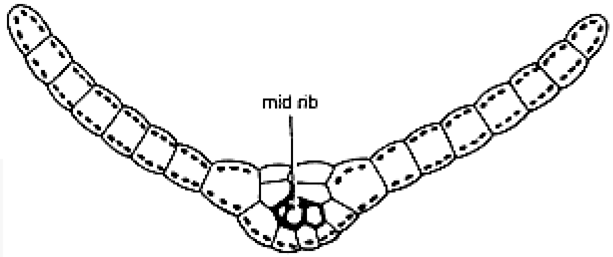


Fig. 3. *Funaria.* Transverse section (T.S.) of 'leaf'

Reproduction in *Funaria*:

It reproduces by vegetative and sexual methods.

Vegetative Reproduction in *Funaria* is performed by the following methods:

(a) Fragmentation of Primary Protonema:

The primary protonema is developed through the germination of the spore. Under certain circumstances, it breaks into several fragments. Each detached fragment bearing buds may grow into a new plant.

(b) Secondary Protonema:

The protonema developing from any part of the plant other than spores are called secondary protonema. Generally, they are formed on injured rhizoids, stems, leaves or reproductive structures. They bear buds that are capable of growing into a new plant (Fig. 6.48B).

(c) Bulbil:

The bulbils are multicellular, brown, bud-like structures that develop on the rhizoidal branches. The bulbils are useful for propagation during unfavourable environmental conditions by detaching them from the parent plants.

(d) Gemmae:

Gemmae (Fig. 6.48B) are multicellular green bodies formed from the terminal cells of the protonema. They remain dormant throughout the unfavourable condition. However, on return of favourable condition, a gemma detaches from the parent plant body and later germinates into a new plant.

(e) Apospory:

Apospory is the condition in which the haploid (n) gametophyte is developed from the diploid (2n) sporophyte without the formation of spores. In case of *Funaria*, gametophytic protonema may develop from any unspecialized cells of the sporophyte. This protonema later, gives rise to gametophyte plant body. Though aposporously develop, gametophytes are normal in appearance, but are diploid (2n). Subsequently, the tetraploid sporophyte develops from the fusion of diploid gametes (2n) are sterile.

Sexual Reproduction in *Funaria*:

Funaria is autoeciously monoecious, because the male (antheridium) and female (archaegonium) reproductive structures develop on separate shoots of the same plant. Antheridia are borne on the main shoot of the plant. The female branch develops as a side shoot (Fig. 6.53), which grows more vigorously and becomes longer than the male branches.

Antheridium:

The antheridia are borne in clusters at the apex of the main axis. A number of long multicellular hairs, called paraphyses are intermingled with the antheridia (Fig. 6.53). Both antheridia and paraphyses are surrounded by a number of bract-like leaves forming a rosette called the perichaetium. The paraphyses have swollen tips (capitate) and contain chloroplasts. Besides their photosynthetic function, paraphyses protect the young antheridia against desiccation. The paraphyses assist in the liberation of antherozoids.

Development of the Antheridium: (NOT FOR EXAM)

The antheridium develops from a superficial antheridial initial located at the tip of the male branch (Fig. 6.49A-G). It becomes papillose and projects above. It divides by a transverse wall to form an outer cell and a basal cell. The outer cell divides further by successive transverse divisions to form a linear filament of 2 to 4 cells.

The terminal cell of the filament divides by two vertical intersecting walls to form a wedge-shaped apical cell with two cutting faces. It forms segments in two rows in alternate sequence. Each young segment of the upper 3 to 4 cells now divides by a vertically diagonal wall to form two unequal cells.

The smaller peripheral cells are the first jacket initials. While, the larger sister cell, by a similar division, forms the outer second jacket initials and the inner primary androgonial cell.

The primary androgonial cell divides and re-divides to form androcyte mother cells. Each androcyte mother cell divides to form two androcytes. The androcytes transform into biflagellate antherozoids or sperms (Fig. 6.49H).

Antheridia in an antheridial head mature at the different times. The jacket initials only divide anticlinally to form a single- layered antheridial jacket.

Mature Antheridium:

A mature antheridium has a multicellular long stalk and a red or orange coloured club-

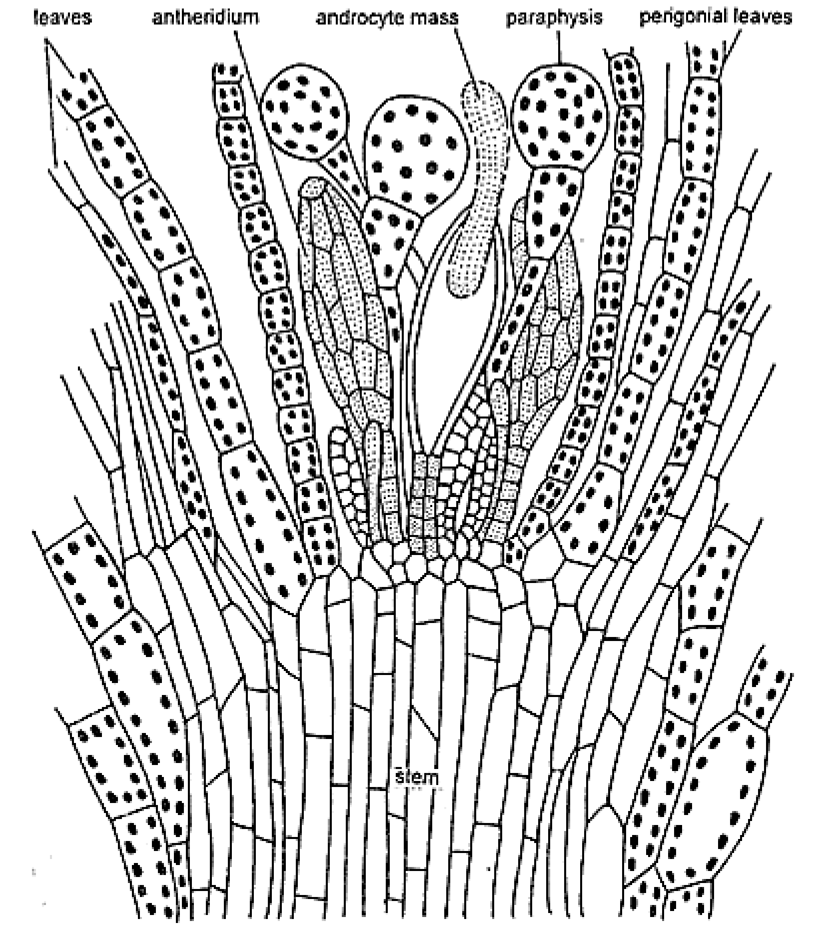
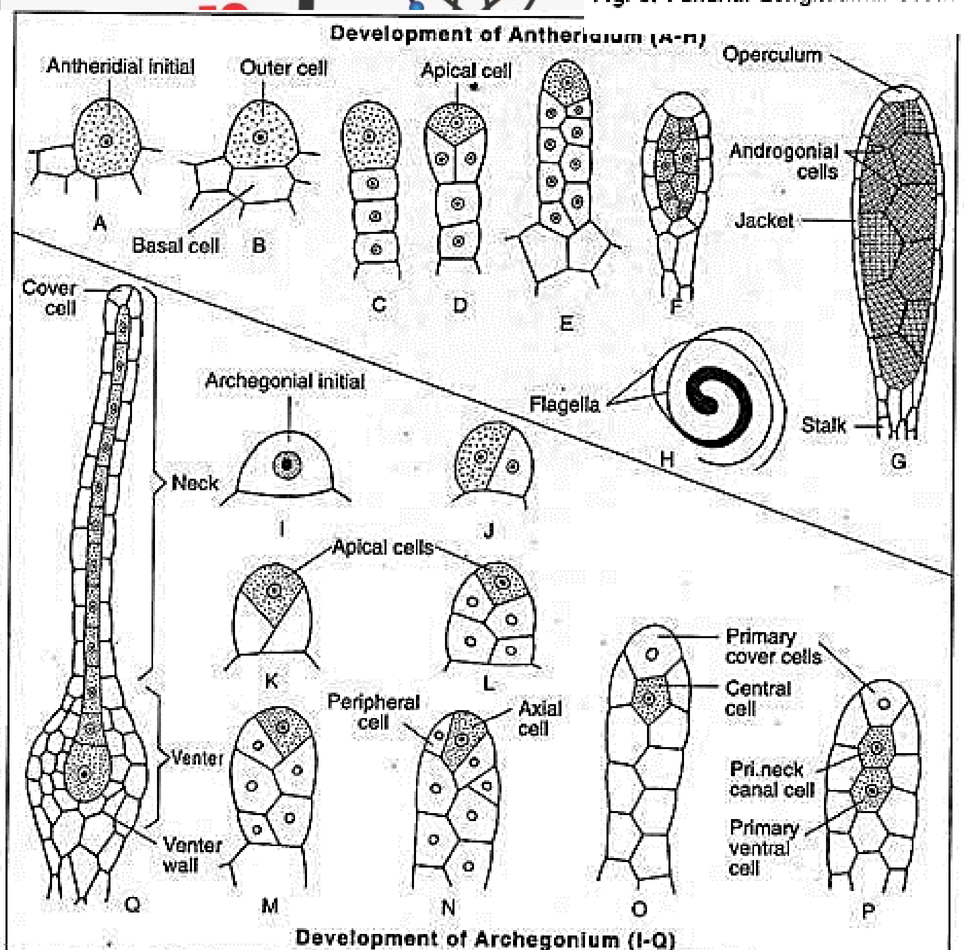


Fig. 5. *Funaria*. Longitudinal Section (L.S.) of male brach showing antheridia.



6.49 : *Funaria hygrometrica* : A-G. Development of antheridium, H. A sperm, I-P. Development of archegonium, Q. A mature archegonium

shaped body (Fig. 6.49G & 6.53). The apical cell of the jacket forms a thick-walled, hyaline operculum or cap of the antheridium.

Dehiscence of the Antheridium: (NOT FOR EXAM)

The dehiscence of the mature antheridium only takes place in presence of water. The opercular cell absorbs dew or rain water and swells up. The pressure thus created ruptures the inner wall and eventually a pore is formed at the distal end of the antheridium.

The androcytes spread out through the pore in the form of a viscous fluid due to the hygroscopic pressure developed within the antheridial cavity (Fig. 6.53).

Archegonium:

The archegonia are borne in clusters at the apex of the archegonial branch (Fig. 6.53).

Development of the Archegonium: (NOT FOR EXAM)

A cell at the tip of the female shoot differentiates into the archegonial initial. It divides transversely to form a upper cell and a lower cell (Fig. 6.49I, J). The upper cell becomes the archegonial mother cell which divides by two intersecting oblique walls forming an apical cell with two cutting faces (Fig. 6.49K).

The apical cell further divides by three intersecting oblique walls to form three peripheral cells surrounding a central axial cell (Fig. 6.49L). The peripheral cells divide anticlinally to form a single-layered jacket (Fig. 6.49M) which, by further divisions, becomes double-layered.

The axial cell divides by a transverse wall to form an outer primary cover cell and an inner central cell (Fig. 6.49N, O). The central cell, by further transverse division gives rise to an outer primary neck canal cell and an inner primary ventral cell.

Primary neck canal cell, by further transverse divisions, forms a row of neck canal cells. The primary ventral cell, by further transverse divisions, forms a ventral canal cell and an egg (Fig. 6.49P, Q).

The primary cover cell cuts off successively three lateral segments and a basal segment. The lateral segments form the jacket of the neck, while the fourth basal segment forms neck canal cells.

Thus, the single-layered long neck of the archegonium of *Funaria* have double origin, one from primary cover cell and the other from central cell.

Mature Archegonium:

The mature archegonium consists of a long stalk, a basal swollen venter and an elongated neck (Fig. 6.49Q & 6.53). The twisted and tubular neck encloses 4 to 10 or more neck canal cells. The archegonial jacket is single-layered thick in the neck region, but it is double-layered in the region of the venter. The venter contains a ventral canal cell and an egg.

Fertilisation of Archegonium:

During fertilisation, the ventral canal cell and the neck canal cells of the archegonium disintegrate forming a mucilaginous substance. This mucilaginous substance absorbs water accumulated as rain or dew water, then swells up and the resultant pressure breaks apart the terminal cover cell. Now sugar containing mucilaginous substances ooze out through the opening of the archegonial neck.

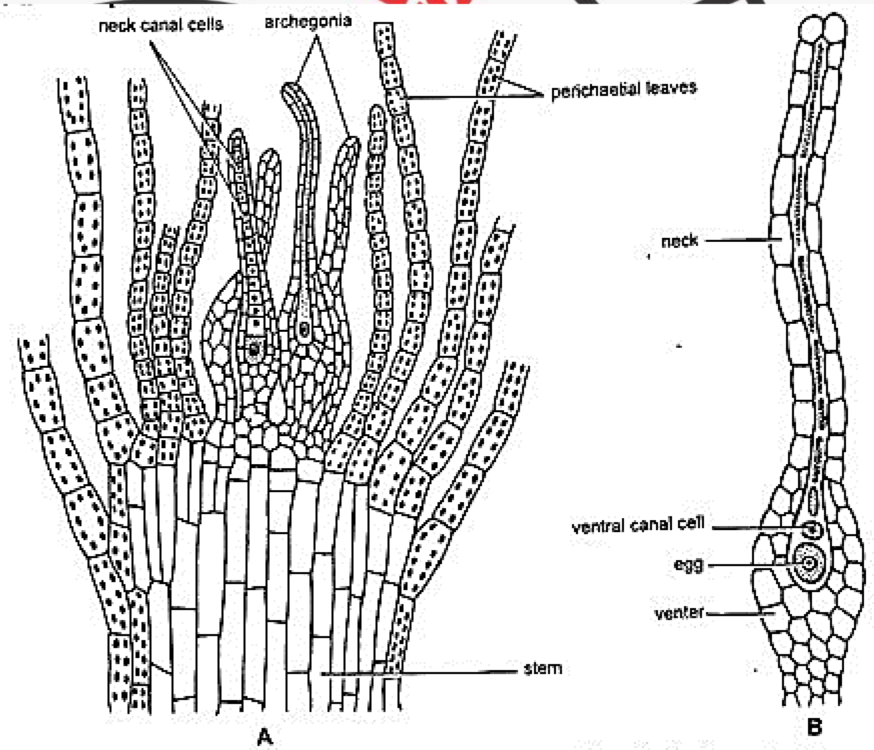


Fig. 7. (A, B). *Funaria*. (A) Longitudinal section (L.S.) of female branch showing archegonia, (B) a mature archegonium.

The liberated antherozoids are now attracted chemotactically towards the archegonia. A large numbers of antherozoids enter the neck, but only one of them fuses with the egg nucleus to form the diploid zygote.

The Sporophyte:

The fertilised egg or zygote is the first cell of the sporophytic generation. The zygote swells up, increases in size and forms a wall around it prior to further divisions.

Development of Sporophyte: (NOT FOR EXAM)

Soon after fertilization, the zygote secretes a wall around it and enlarges in size. It divides by a transverse wall forming an upper epibasal cell and lower hypo basal cell (Fig. 12 A, B). Epibasal cell divides by two intersecting oblique walls. It differentiates an apical cell with two cutting faces in the epibasal cell (Fig. 12C). Similarly, the hypo basal cell differentiates an apical cell (Fig. 12 D).

The entire sporophyte is differentiated by the activity of these two apical cells. So, the development of embryo sporophyte is bi-apical. Epibasal apical cell develops into capsule and upper portion of the seta while the hypo basal apical cell develops into foot and remaining part of the seta. Both apical cells cut out alternate segments and form the elongated filamentous structure of young sporogonium (Fig. 12 E, F).

Development of Capsule: (NOT FOR EXAM)

A cross section through the upper portion of the young sporogonium shows a two identical segments (Fig. 13A) which divide by a vertical division at right angle to the previous one to form a quadrant (4 celled stage) (Fig. 13B).

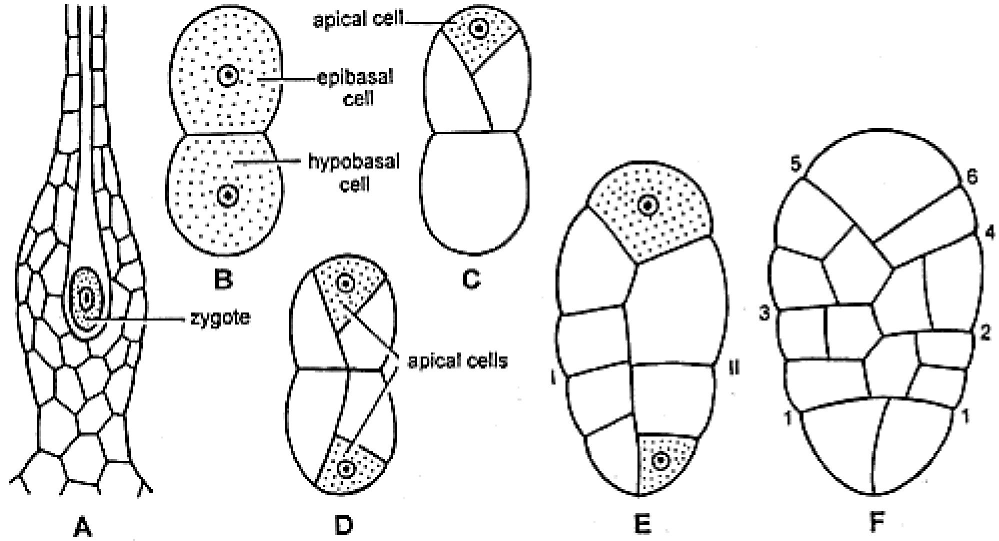


Fig. 12. *Funaria.* Early stages in the development of sporophyte.

Each cell of the quadrant divides by anticlinal wall (Fig. 13C) in such a way that a smaller almost triangular cell and a larger more or less rectangular cell is formed. Each rectangular cell now divides by a periclinal division (Fig. 13D).

It results in formation of a group of four central cells surrounded by 8 peripheral cells. The central tissue is known as endothecium and the peripheral cells form the amphithecium (Fig. 13D). From these two group of cells the further development takes place. There is formation of different rings by anticlinal and periclinal divisions.

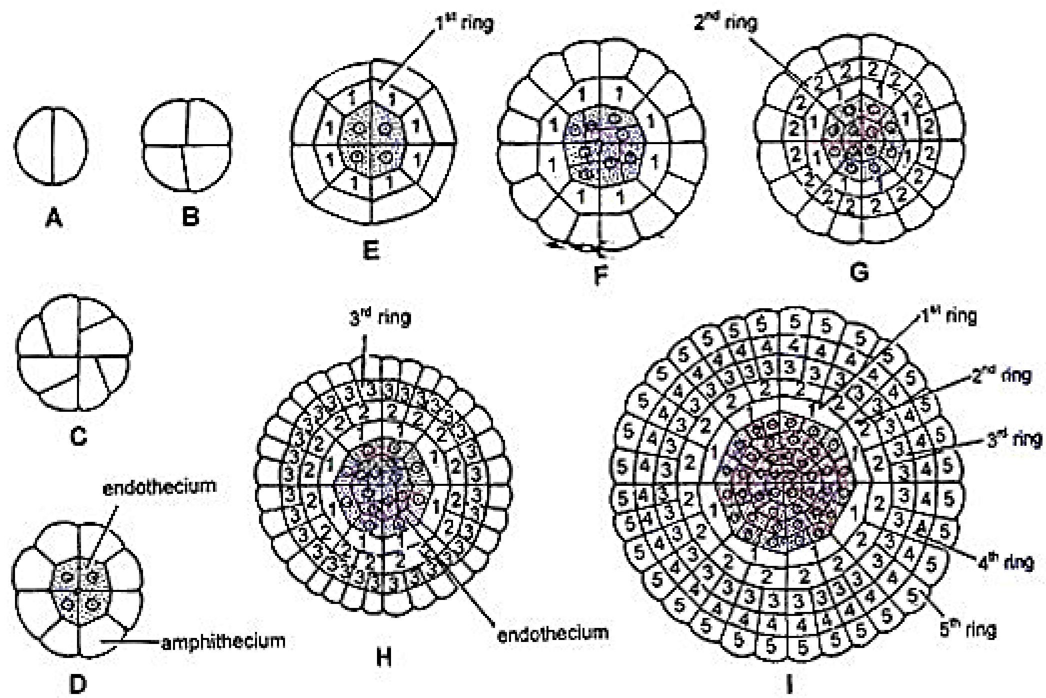


Fig. 13. (A–I). *Funaria.* Various stages in the development of capsule.

The amphithecium divides by periclinal division to form two concentric layers. The inner layer of 8 cells is called first ring (Fig. 13E). The cells of the outer layer divide by anticlinal divisions to form 16 cells (Fig. 13F). This is followed by the periclinal division in this layer.

The inner part of this layers is called the second ring (Fig. 13G). Again the outer layer of these two layers divides anticlinally to form 32 cells. This layer divides periclinally to form two layers of 32 cells. The inner layer is called third ring. Similarly by periclinal divisions fourth and fifth ring of 32 cells are formed (Fig. 13G-I).

The four cells of the endothecium also divides similarly to amphithecium. The first division is curved and anticlinal (Fig. 13F). The second division is periclinal (Fig. 13G). It results in the formation of a central group of 4 endothecial cells, surrounded by 8 peripheral endothecial cells. Further development of the tissues in the capsule region takes place by these amphithecial rings and endothecial cells.

The fertile region in capsule comprises archesporium lined by outer and inner spore sac. Archesporium is endothecial in origin. Its cells may undergo sub-divisions to form two cell layers thick spore mother cells which by meiosis form tetrad of spores. Elaters are absent.

Structure of the Mature Sporophyte:

The mature sporophyte of *Funaria* is differentiated into a foot, a long seta and a pear- shaped capsule at the tip.

1. Foot:

It is a poorly developed conical structure, embedded in the apex of archegonial branch.

2. Seta:

Seta is long, green in colour when young, but becomes reddish brown at maturity. T.S. of seta shows a single-layered epidermis, a central conducting strand of thin-walled cells surrounded by a cortex made up of comparatively thick-walled cells (Fig. 6.50A). Seta helps in conduction of nutrients and water from gametophyte to capsule.

3. Capsule:

The mature capsule is pear shaped, asymmetrical (Fig. 6.50B, C). Internally, it is divided into three distinct parts viz., the sterile basal region, the apophysis, the central fertile region, the theca and the apical region.

Apophysis:

The lowermost part of the capsule is the apophysis or the neck that connects it with the seta below. The axis of the apophysis shows in the lower part a central strand of thin-walled elongated cells connected with the similar tissue of the seta.

Loosely arranged chlorophyllous cells are bounded by a rather thick-walled epidermis which is interrupted by the stomata (Fig. 6.50C).

The presence of chlorophyllous tissue in the apophysis makes the sporophyte carry out photosynthesis. Therefore, the sporophyte of *Funaria* is not fully dependent on the gametophyte for nutrition.

The Theca or Fertile Zone:

The central zone of the capsule situated in between the apophysis and the operculum is called the theca.

It is a slightly bent cylindrical structure, fertile in nature and has four distinct regions:

(a) Capsule wall,
(b) Spore-sacs
(c) Air chamber
(d) Columella.

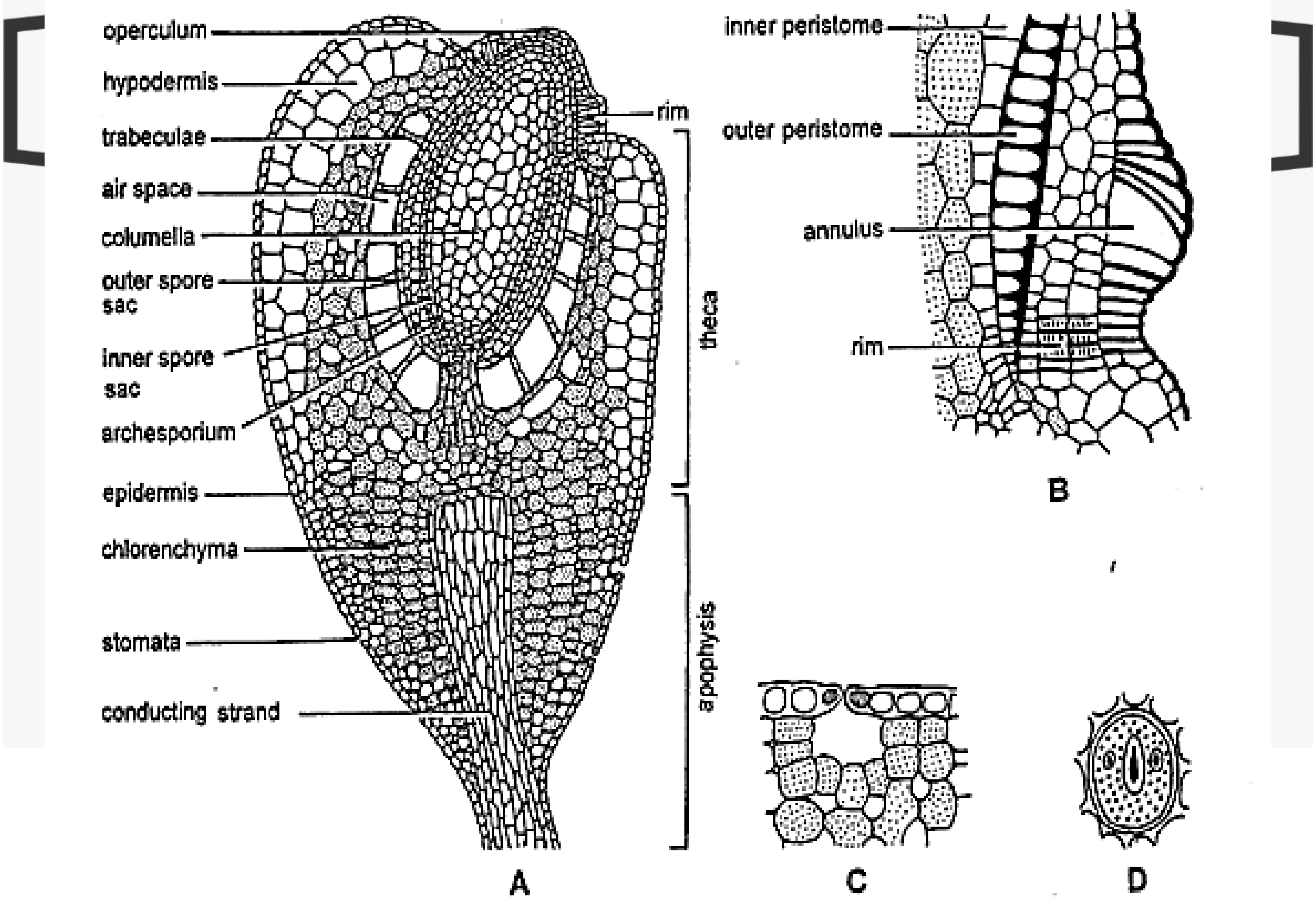


Fig. 11. (A–D). *Funaria*. Internal structure of the capsule. (A) Longitudinal Section (L.S.) of entire capsule, (B) L.S. through annulus region, (C) Structure of stomata in L.S., (D) Stomata in surface view.

(a) Capsule Wall:

The capsule wall is many-layered. The single-layered outermost wall forms the epidermis which is followed by a 2-3 layered parenchymatous hypodermis (Fig. 6.50C). The inner 2-3 layers of parenchymatous cells are chlorophyllous, which constitute the photosynthetic tissue of the capsule.

(b) Spore Sacs:

The columella is surrounded by two elongated spore-sacs (Fig. 6.50C). The spore-sac has a inner wall of one layer of small cells and an outer wall of 3 to 4 layers of such cells. The spore sacs are formed from the single layered archesporium. Archesporium first develops 6-8 layers of sporogenous cells. The sporogenous layer becomes a spore-sac by the production of spores from spore mother cells through meiotic divisions.

(c) Air Chamber:

The outer wall of the spore-sac is followed by a big cylindrical air chamber. It is traversed by strings of filaments of elongated green cells, known as trabeculae which bridges the air space between the outer wall of the spore-sac and the innermost layer of the capsule wall (Fig. 6.50C).

(d) Columella:

It is the central, axial part of the fertile zone, comprising of thin-walled, colourless, compact, parenchymatous cells, constricted at the base just above the apophysis (Fig. 6.50C). The distal part of the columella is cone-shaped which projects into the concavity of the operculum. The columella serves the purpose of conduction of water and nutrients to the growing sporophyte.

The Apical Region:

The apical region of the capsule is a complicated structure. This joins the capsule proper through a notch (Fig. 6.50B, C). An annular rim (or diaphragm) of 2-3 layers of radially elongated small cells is present at this notch. The diaphragm demarcates the upper limit of the theca proper.

The operculum is an obliquely placed, dome-shaped lid that closes the mouth of the capsule (Fig. 6.50B). It is composed of 2 to 3 layers of thin-walled parenchymatous cells (Fig. 6.50C). The lower part of the operculum forms a ring of slightly large conspicuous cells, the annulus. The operculum keeps the peristome teeth covered, while the annulus helps in the dehiscence of the capsule.

The peristome teeth lies just below the operculum and are attached beneath the edge of the diaphragm. It consists of two rings of long triangular teeth, one within the other (Fig. 6.51 A, B). The teeth are not cellular in nature and are made up of cuticle.

Each ring of peristome possesses 16 teeth. The outer teeth (exostome) are larger, thicker, brown in colour and ornamented with transverse thickening bands. The inner peristome teeth (endostome) are small, delicate and of a pale colour.

The whole structure is called peristome which is epicranoid in nature, because the outer peristome teeth are superposed on the inner ring. The tapering distal ends of the outer peristome teeth are joined to a centrally placed disc of tissue (Fig. 6.50B & 6.51 A).

Dehiscence of the Capsule and the Dispersal of Spores: (NOT FOR EXAM)

At maturity, the operculum begins to dry up due to the non-availability of water supply to the capsule. Consequently, the thin-walled cells of the operculum, including the annulus which hold the operculum in place, shrink and shrivel. Ultimately, the annulus breaks and the loosened operculum is thrown away leaving the peristome teeth exposed (Fig. 6.50B).

The peristome teeth are twisted spirally appearing like an iris diaphragm (Fig. 6.50B).

The outer peristome teeth are hygroscopic which show inward or outward movements according to the presence or absence of moisture in the environment. During dry atmosphere, the outer peristome teeth bend outwards with jerky movements.

The slits between the inner peristome teeth widens due to the outward movements of the outer peristome teeth, thus allowing the spores to escape through these slits. In high humidity, the hygroscopic teeth of the outer peristome absorb water and bend inwards and close the slits. This prevents the escape of spores in wet weather.

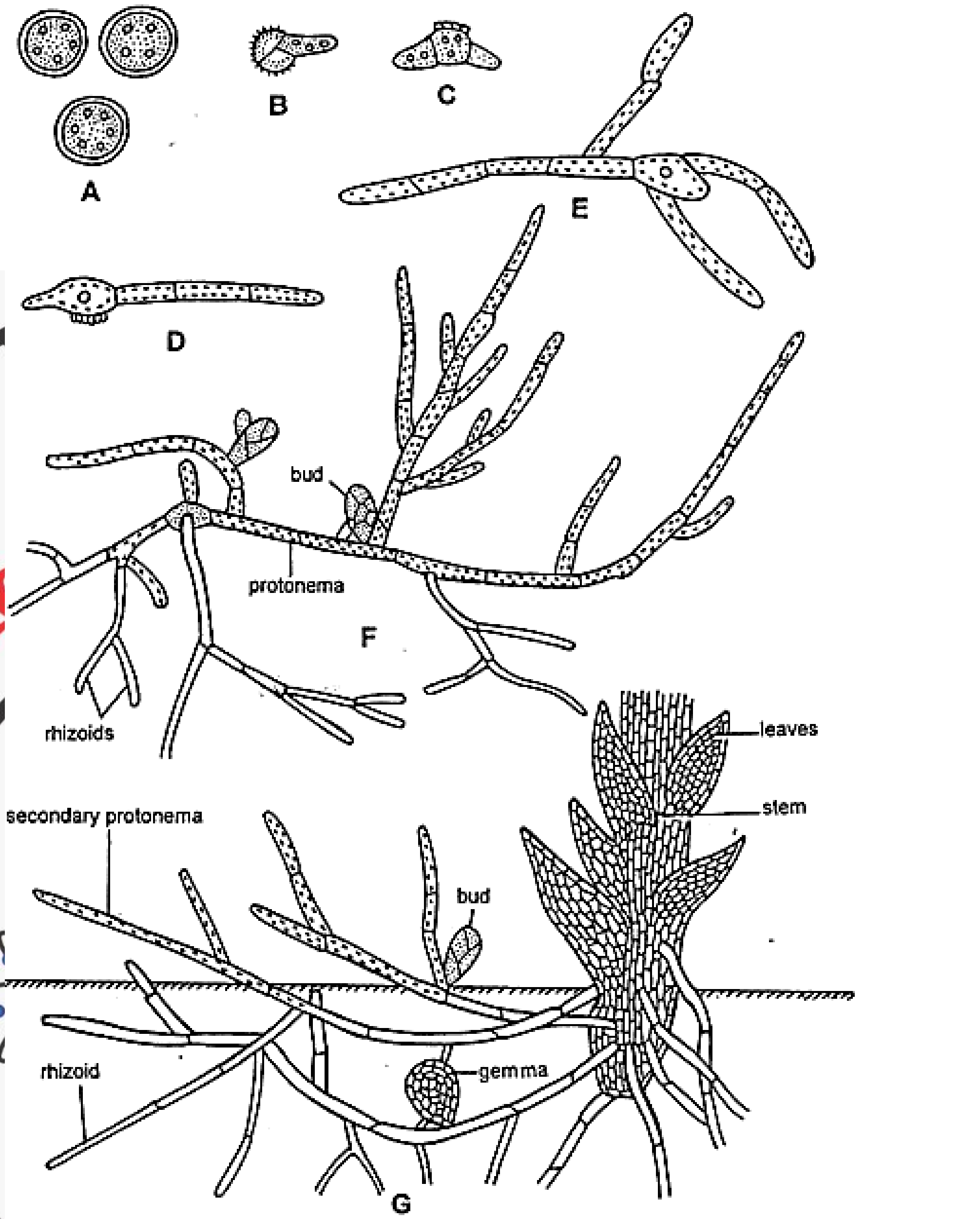
The young sporophyte is covered by calyptra that develops from the old archegonial venter wall. It protects the capsule from drying and sheds prior to its dehiscence.

The New Gametophyte:

The haploid spore is the first cell of the gametophytic generation. It is small, spherical, measuring 12-20 pm in diameter. The spore wall is differentiated into an outer thick, brown coloured exine (exosporium) and an inner thin, colourless intine (endosporium) (Fig. 6.52A).

Under favourable environmental conditions the spore germinates. The exine is ruptured and the intine protrudes out as a germ tube (Fig. 6.52B, C). The germ tube elongates, becomes septate and produces a filamentous protonema (Fig. 6.52D, E). The protonema branches freely and forms two types of branches viz., chloronemal branches and rhizoidal branches (Fig. 6.52F). The chloronemal branches possess conspicuous chloroplasts in their cells and become green in colour which are either erect or very close to the substratum that form the partition walls at right angles to the lateral walls. The rhizoidal branches develop below the substratum, brown in colour and the partition walls are oblique to the lateral wall. The rhizoidal filaments are primarily meant for anchoring the protonema in the substratum.

The chloronemal branches develop many minute buds (Fig. 6.52F) and each bud grows into an erect leafy gametophore. They become independent shortly after the death of the protonema. A dense growth of the plants are observed because of this property. An young gametophyte comprises of leafy stem, rhizoids arid protonema.



Funaria. (A–G). (A) spores, (B–F) Stages in the germination of spores and formation of primary protonema, (G) Secondary protonema.

Fig. 17 depicts the diagrammatic representation of the life cycle of *Funaria hygrometrica*.

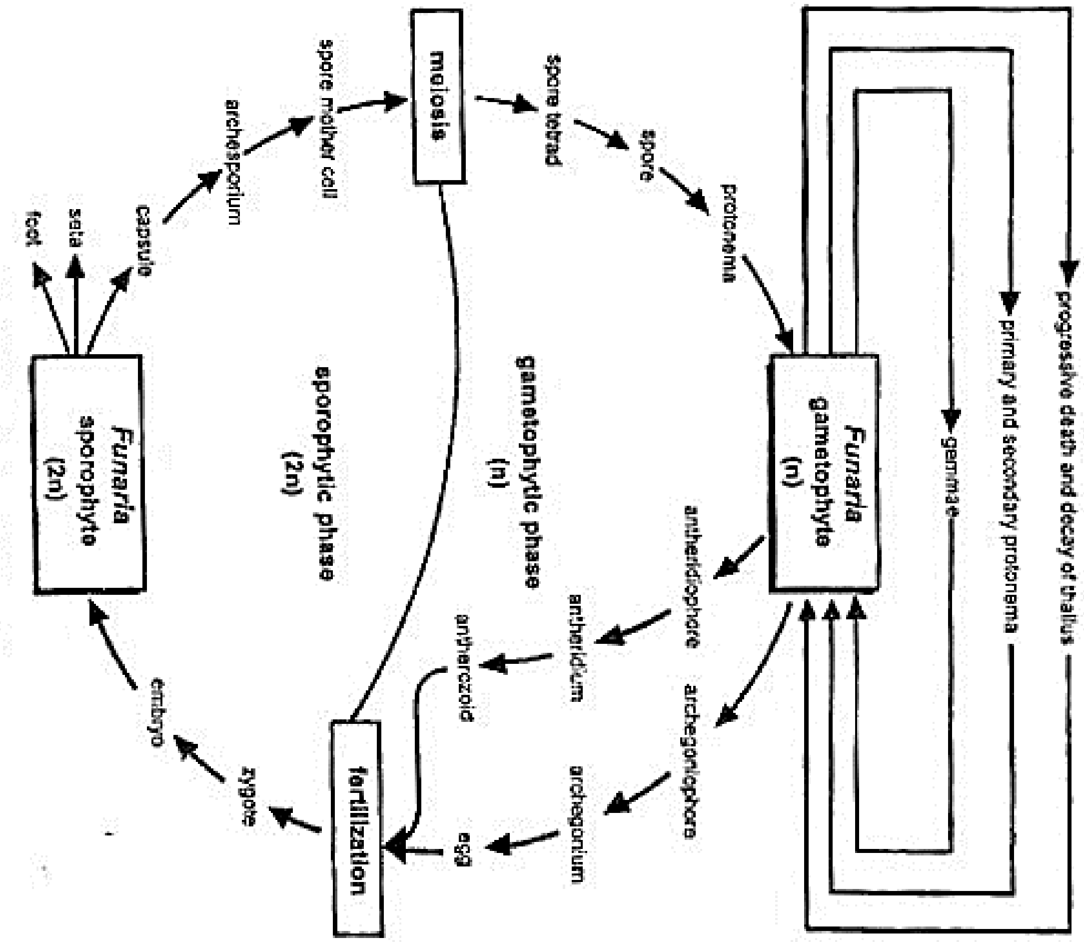


Fig. 18. *Funaria*. Graphic life cycle.

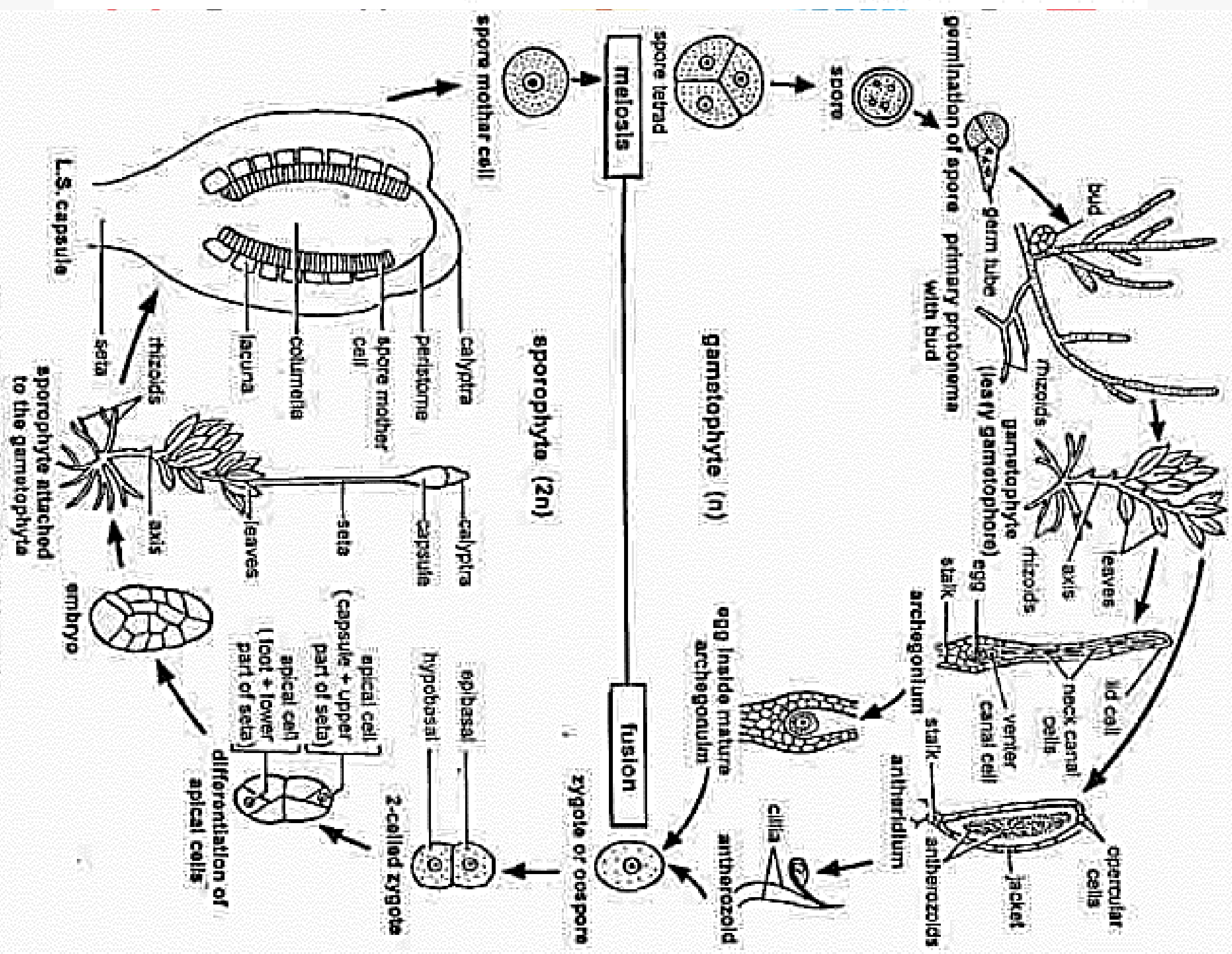


Fig. 17. *Funaria*. Diagrammatic life cycle.